NUWC-NPT Technical Report 11,899
28 October 2008

Assessing Potential Sites for Undersea Warfare Training Ranges: The Effects of Active Sonars on Marine Mammals

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NEWPORT

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PREFACE

This report was prepared under Project Number C744088. The sponsoring activity is the Naval Air Systems Command, program manager (PMA-205).

The technical reviewer for this report was Jerry L. Thibodeaux (Code 74).

The authors thank Peter H. Hulton (Code 74) and Roy L. Deavenport (Code 74) for their contributions to the marine mammal acoustic effects modeling effort.

Reviewed and Approved: 28 October 2008

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE (DD-*MM-YY*)	2. REPORT TYPE	3. DATES COVERED (*From – To*)
28-10-2008	Technical Report	

4. TITLE AND SUBTITLE	
Assessing Potential Sites for Undersea Warfare Training Ranges: The Effects of Active Sonars on Marine Mammals	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5.d PROJECT NUMBER C744099
Yadira V. Gilchrest Thomas N. Fetherston Bert E. Neales	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Undersea Warfare Center Division 1176 Howell Street Newport, RI 02841-1708	**8. PERFORMING ORGANIZATION REPORT NUMBER** TR 11,899
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Naval Air Systems Command PMA 205 Patuxent River, MD 20670-1547	**10. SPONSORING/MONITOR'S ACRONYM** NAVAIR
	11. SPONSORING/MONITORING REPORT NUMBER

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The U.S. Navy is preparing a draft environmental impact statement/overseas environmental impact statement (DEIS/OEIS) for what will be the proposed site for an undersea warfare training range (USWTR). The DEIS includes an assessment of the effects of Navy active acoustic sonars on marine mammals during range exercises as required by the Marine Mammal Protection Act (MMPA). The Naval Undersea Warfare Center Division, Newport, RI, has assessed four sites: Jacksonville, FL; Charleston, SC; Onslow Bay, NC; and Wallops Island, VA. This report describes the input data and analysis methods used to estimate the number of marine mammals that could be affected by the operation of Navy tactical acoustic sonar systems at the four potential USWTR sites.

15. SUBJECT TERMS

Undersea Warfare   Marine Mammal Density Estimates   Temporary Threshold Shift   Permanent Threshold Shift
Zone of Influence   Navy Underwater Detonation Training   Level A Harassment Threshold   Level B Harassment Threshold
Reflection and Refraction in Multilayered Ocean/Ocean Bottoms with Shear Wave Effects

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Yadira V. Gilchrest
Unclassified	Unclassified	Unclassified	SAR	84	19b. TELEPHONE NUMBER (*Include area code*) 401-832-4233

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

EXECUTIVE SUMMARY

The U.S. Navy is preparing a draft environmental impact statement/overseas environmental impact statement (DEIS/OEIS) for what will be the proposed site for an undersea warfare training range (USWTR). The DEIS includes an assessment of the effects of Navy active acoustic sonars on marine mammals during range exercises as required by the Marine Mammal Protection Act (MMPA). The Naval Undersea Warfare Center (NUWC) Division, Newport, RI, has completed this assessment for four sites: the preferred site of Jacksonville, FL, and the alternate sites of Charleston, SC, Onslow Bay, NC, and Wallops Island, VA.

This report describes the input data and analysis methods used to estimate the number of marine mammals that could be affected by the operation of Navy tactical acoustic sonar systems at the four potential USWTR sites. Unlike an earlier analysis of acoustic effects on marine mammals for three proposed range sites,* this analysis incorporates risk function criteria in accordance with the Chief of Naval Operations Environmental Readiness Division (CNO (N-45)).

The input data that are essential to the methodology used to estimate the number of marine mammals that could be affected by the Navy tactical acoustic sonar systems fall into five categories: (1) Navy training requirements, (2) acoustic source data, (3) acoustic environment, (4) marine mammal populations, and (5) acoustic effects definitions.

The training scenarios were generated with guidance from the Navy to capture the scope and volume of training planned on a yearly basis. The acoustic source operational characteristics were collated by NUWC Division Newport from numerous sources, including Atlantic and Pacific Fleet commands, systems operating guidelines, and technical design documentation. Geophysical data were compiled by NUWC Division Newport from multiple sources, primarily National Oceanographic and Atmospheric Administration (NOAA) databases. The marine mammal density estimates were obtained from Department of the Navy operating area (OPAREA) density estimates (NODE) report for the Southeast. A Navy panel convened by the CNO (N-45) defined the marine mammal harassment criteria (Level A and Level B harassment thresholds).

To estimate marine mammal harassment exposures, the total harassment area for each source is converted to a species harassment rate (that is, harassment areas multiplied by the corresponding mammal population densities). This process is performed for each species for both Level A harassment and Level B harassment thresholds. Level A harassment areas are subtracted from Level B harassment areas to prevent double-counting incidents. For the same reason, harassment areas between 195 and 215 dB re 1 μPa sound exposure level (SEL), representing Level B temporary threshold shift (TTS) exposures, are also subtracted from the remaining Level B harassment area before the risk function curves are applied. The total number of potential Level B harassment exposures is calculated by adding the TTS exposures with the

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* Jette, S.D., J. Cembrola, G. H. Mitchell, and T. N. Fetherston (2005), "Analysis of Acoustic Effects on Marine Mammals for the Proposed Undersea Warfare Training Range," NUWC-NPT Technical Report 11,712, Naval Undersea Warfare Center Division, Newport, RI.

risk function exposures. For the purposes of this report, however, these two exposures are reported separately.

The final estimated number of exposures depends on the input values for each of the parameters. Each category has a varying degree of confidence and stability with time. For example, mammal density estimates may be derived from sparse data. Conversely, the yearly training activity is precisely quantified. The goal was an unbiased prediction of the number of exposures that are expected over 1 year's training, given these diverse and variable factors. Average or typical values were emphasized. The estimates do not represent an absolute guarantee of the interaction of sound and mammals on a day-to-day or annual basis.

The estimated annual takes for Level B harassment (including TTS and behavioral) at Jacksonville, Charleston, Onslow Bay, and Wallops Island were 106,407, 8196, 42,324, and 151,053, respectively. At all sites, the most annual exposures are attributed to surface ship sonars, particularly the AN/SQS-53. The remaining exposures are attributed to the operation of torpedo sonars, helicopter dipping sonars, Directional Command Active Sonobuoy System (DICASS) sonobuoys, acoustic device countermeasures, anti-torpedo decoys, surface ship fathometers, submarine fathometers, and submarine sonars. Level A harassment was estimated to be 7 at Jacksonville, 0 at Charleston, 2 at Onslow Bay and 10 at Wallops Island. Level A harassment is thought to be unlikely because of the small harassment areas and nearfield effects in proximity to the larger sonar. In addition, standard operating procedures to avoid ship strikes of mammals simultaneously mitigate Level A harassment.

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LIST OF ABBREVIATIONS AND ACRONYMS

ADCAP	Advanced Capability
ADC	Acoustic device countermeasure
ADD	Acoustic deterrent device
ADH	Acoustic harassment device
AE	Acoustic energy
AHA	Active hemispherical array
ALFS	Airborne Low-Frequency Sonar
ALW	Advanced Capability Lightweight
APL/UW	Applied Physics Laboratory/University of Washington
ASW	Antisubmarine warfare
CASS	Comprehensive Acoustic System Simulation
CHPT	Cherry Point
CM	Countermeasure
CNO	Chief of Naval Operations
COMPTUEX	Composite training unit exercise
CW	Continuous waveform
DBDB-V	Digitized Bathymetric Data Base-Variable
DEIS	Draft environmental impact statement
DICASS	Directional Command Active Sonobuoy System
DoN	Department of the Navy
EIS	Environmental impact statement
EMATT	Expendable Mobile ASW Training Target
EXTORP	Exercise torpedo
fm	Fathom
FM	Frequency modulation
GDEM-V	Generalized Digital Environmental Model
GIS	Geographic Information Systems
GPS	Global positioning system
GRAB	Gaussian Ray Acoustic Bundle
HFA	High-frequency array
HF	High frequency
HRC	Hawaii Range Complex
INDEX	Independent deployer exercise
JAX/CHASN	Jacksonville/Charleston
JTFEX	Joint task force exercise
LAMPS	Light Airborne Multipurpose System
LF	Low frequency
LFA	Low-frequency active
LFBA	Low-frequency bow array
LFBLTAB	Low-frequency bottom loss
LFS SRP	Low-Frequency Sound Scientific Research Program

LIST OF ABBREVIATIONS AND ACRONYMS (Cont'd)

LSA	Large spherical array
MF	Medium (Mid) frequency
MFA	Midfrequency active
MGS	Marine Geophysical Survey
MIDAS	Mine/ice detection and avoidance system
MMPA	Marine Mammal Protection Act
MRA	Marine Resource Assessment
NA	Not applicable
NAVOCEANO	Naval Oceanographic Office
NDBC	National Data Buoy Center
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration
NODC	National Oceanographic Data Center
NODE	Navy OPAREA density estimates
NOO	Naval Oceanographic Office
NUWC	Naval Undersea Warfare Center
OAML	Oceanographic and Atmospheric Master Library
OEIS	Overseas environmental impact statement
OPR	Office of Protected Resources
OPAREA	Operational area
Pa	Pascal
PE	Parabolic equation
PTS	Permanent threshold shift
REXTORP	Recoverable exercise torpedo
RL	Receive (d) level
rms	Root-mean-square
SADS	Submarine active detection sonar
SEL	Sound exposure level
SL	Source level
SSC	SPAWAR Systems Center
SPAWAR	Space and Naval Warfare
SPL	Sound pressure level
SPORTS	Sonar Positional Reporting System
SSP	Sound speed profile
SURTASS	Surveillance Towed Array Sensor System
TTS	Temporary threshold shift
UQC	Underwater mobile sound communications
USWTR	Undersea warfare training range
VACAPES	Virginia Capes
WAA	Wide-aperture array

ASSESSING POTENTIAL SITES FOR UNDERSEA WARFARE TRAINING RANGES: THE EFFECTS OF ACTIVE SONARS ON MARINE MAMMALS

1. INTRODUCTION

The U.S. Navy is preparing a draft environmental impact statement/overseas environmental impact statement (DEIS/OEIS) for what will be the proposed site for an undersea warfare training range (USWTR). The DEIS includes an assessment of the effects of Navy active acoustic sonars on marine mammals during range exercises as required by the Marine Mammal Protection Act (MMPA). The Naval Undersea Warfare Center (NUWC) Division, Newport, RI, has completed this assessment for four sites: the preferred site of Jacksonville, FL, and the alternate sites of Charleston, SC, Onslow Bay, NC, and Wallops Island, VA.[*]

This report describes the input data and analysis methods used to estimate the number of marine mammals that could be affected by the operation of Navy tactical acoustic sonar systems at the four potential USWTR sites. Unlike an earlier analysis of acoustic effects on marine mammals for three proposed range sites,[†] this analysis incorporates risk function criteria in accordance with the Chief of Naval Operations (CNO) Environmental Readiness Division (CNO N-45).

The input data that are key to the methodology used to estimate the number of marine mammals that could be affected by the Navy tactical acoustic sonar systems fall into five categories: (1) marine mammal density estimates for the proposed range locations, (2) definitions for Level A and Level B harassment thresholds for Navy sonar systems, (3) geophysical data for the sites, (4) characterization of Navy training scenarios and the military sonars to be used, and (5) operational characteristics for the acoustic sonar systems to be used.

Information on marine mammal density estimates was obtained from the Department of the Navy (DoN) operating area (OPAREA) density estimates (NODE) report for the Southeast (DoN, 2007a). Geophysical data were compiled by NUWC Division Newport from multiple sources. A Navy panel convened by CNO N-45 established the definitions used for the marine mammal harassment criteria for Level A and Level B harassment thresholds.

The training scenarios were defined by the Navy to capture the full scope of activities expected at the range on a yearly basis. The operational characteristics data were collated by NUWC Division Newport from numerous sources, including the Atlantic and Pacific Fleet

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[*] Although site naming conventions were revised in August 2005, the former range naming conventions are used in this report. The DEIS/OEIS Site A is referred to as "Jacksonville"; Site B is referred to as "Charleston"; Site C is referred to as "Onslow Bay"; and Site D is referred to as "Wallops Island."

[†] Jette, S.D., J. Cembrola, G. H. Mitchell, and T. N. Fetherston (2005), "Analysis of Acoustic Effects on Marine Mammals for the Proposed Undersea Warfare Training Range," NUWC-NPT Technical Report 11,712, Naval Undersea Warfare Center Division, Newport, RI.

commands, systems operating guidelines, and technical design documentation. Only the unclassified input data are summarized in this report.

This report describes how the analysis was conducted: the Marine Mammal Acoustic Effects Model calculates the area for which each source produces a sound exposure level (SEL) at or above the defined Level A and Level B harassment thresholds. This area was calculated for each combination of training scenario, source, and season. To estimate marine mammal harassment exposures, the total harassment area for each source is converted to a species harassment rate (that is, harassment areas multiplied by the corresponding mammal population densities). This process is performed for each species for both Level A harassment and Level B harassment thresholds. Level A harassment areas are subtracted from Level B harassment areas to prevent double-counting incidents. For the same reason, harassment areas between 195 and 215 dB re 1 μPa SEL, representing Level B temporary threshold shift (TTS) exposures, are also subtracted from the remaining Level B harassment area before the risk function curves are applied. The total number of potential Level B harassment exposures is calculated by adding the TTS exposures with the risk function exposures. For the purposes of this report, however, these two exposures are reported separately. A summary of the input data for this methodology is provided in figure 1-1, and a modeling flowchart is shown in figure 1-2.

Figure 1-1. Summary of Analysis Input Data

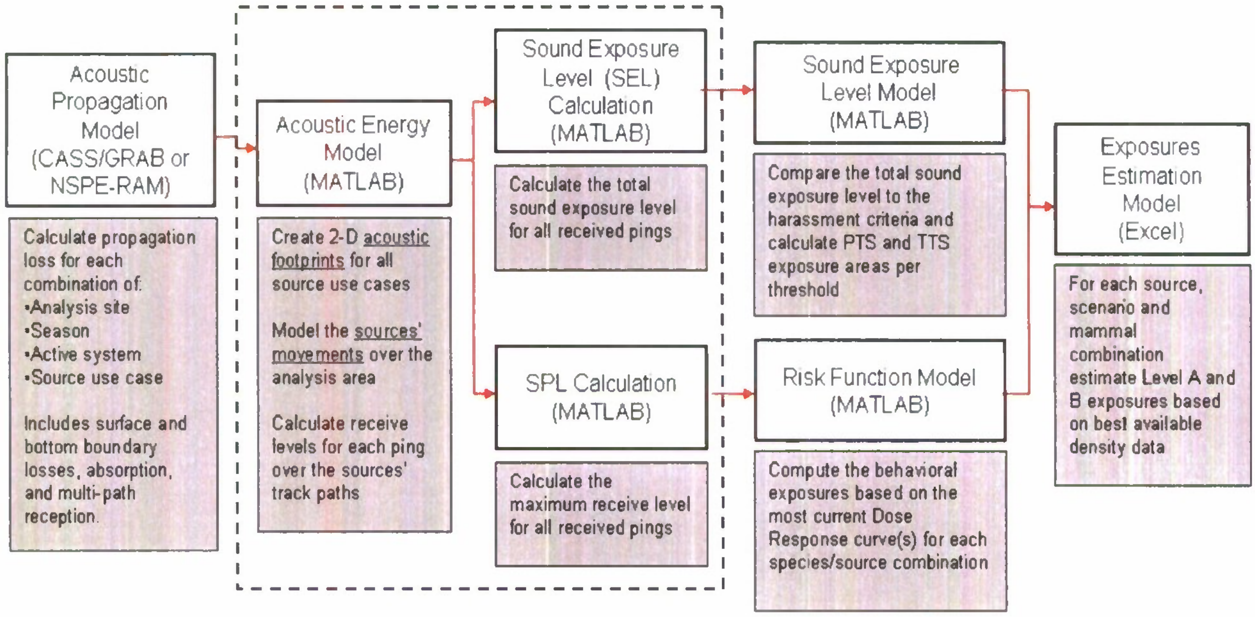

Figure 1-2. Summary of Models, Modeling Steps, and Software Platforms

The final results are "estimated numbers of exposures" and are summarized by harassment thresholds for the respective sonar system, scenario, and species. The final results depend on definitions made for the methodology that bound the volume of analysis; without such constraints, the number of variations that could be modeled would be nearly infinite. The use of defined ship tracks, specific acoustic propagation analysis points, representative training scenarios, and typical source characteristics are all examples of this point. The goal was an unbiased prediction of the number of exposures expected over a 1-year training period, given these diverse and variable factors. These predictions are not an absolute guarantee of the interaction of sound and mammals on a day-to-day or annual basis since variations can occur relative to the modeled parameters. Instead, the results represent an expected average.

2. DISTRIBUTION AND ABUNDANCE OF MARINE MAMMALS AT THE PROPOSED USWTR LOCATIONS

One important aspect in the evaluation of potential effects on marine mammals in any given area is a thorough understanding of the distribution and abundance of the mammals within that area. The information on species distribution relies heavily on data gathered in the Marine Resource Assessment (MRA). The Navy MRA Program was implemented by the Commander, Fleet Forces Command to initiate collection of data and information concerning protected and commercial marine resources found in the Navy's OPAREAs. Specifically, the goal of the program is to describe and document the marine resources present in each of the Navy's OPAREAs. MRAs were updated for the Virginia Capes (VACAPES), Cherry Point (CHPT), and Jacksonville/Charleston (JAX/CHASN) in 2007 (DoN, 2007b). The VACAPES OPAREA includes the alternate location offshore of Wallops Island, VA; the CHPT OPAREA includes the alternate location offshore of Onslow Bay, NC. The updated marine mammal densities are contained in the Navy OPAREA Density Estimates (NODE) for the Southeast OPAREAs (DoN, 2007a). This report provides a compilation of the most recent data and information on the occurrence, distribution, and density of marine mammals in the southeast. Additional information on how the density estimates were derived can be found in the NODE report for the Southeast OPAREAs (DoN, 2007a).

The updated density information extracted from the NODE report utilizes Geographic Information Systems (GIS) to create a density map estimate for each OPAREA. In contrast, the marine mammal density estimates used by Jette et al. (2005) were stratified by depth to further represent distributions and relative concentrations of species within regions.

2.1 TEMPORAL DISTRIBUTION

Training at the proposed locations may occur throughout the year. To account for seasonal variability in the temporal distribution of marine mammals, it was necessary to partition the year appropriately. Density estimation was calculated by seasons, which were defined in the following manner: winter (December through February), spring (March through May), summer (June through August), and fall (September through November).

2.2 SPATIAL DISTRIBUTION

Distributions of marine mammals are frequently characterized by association with various depth strata and are closely linked to habitat use or resource exploitation. Because the USWTR straddles the shelf edge and includes adjacent waters, it was necessary to apply the density estimates according to how species were likely to occupy the regions. The USWTR and adjacent waters include two of four defined strata, mid-shelf and shelf-edge waters, and do not include near-shore and shelf-slope waters. The four strata are defined as follows: (1) near-shore waters (< 20 fm (not included in USWTR)), (2) mid-shelf waters (20 – 49 fm), (3) shelf-edge waters (50 – 1099 fm, and (4) shelf-slope waters (> 1100 fm (not included in USWTR)).

The NODE report for the Southeast OPAREAs (DoN, 2007a) provides the density estimates as marine mammal density maps, which distribute the animals across the OPAREA according to GIS layers and depth strata. Density maps provide a more accurate representation of marine mammal distribution on the range. An example of a density map for the Atlantic spotted dolphin in the Jacksonville OPAREA during fall is displayed in figure 2-1.

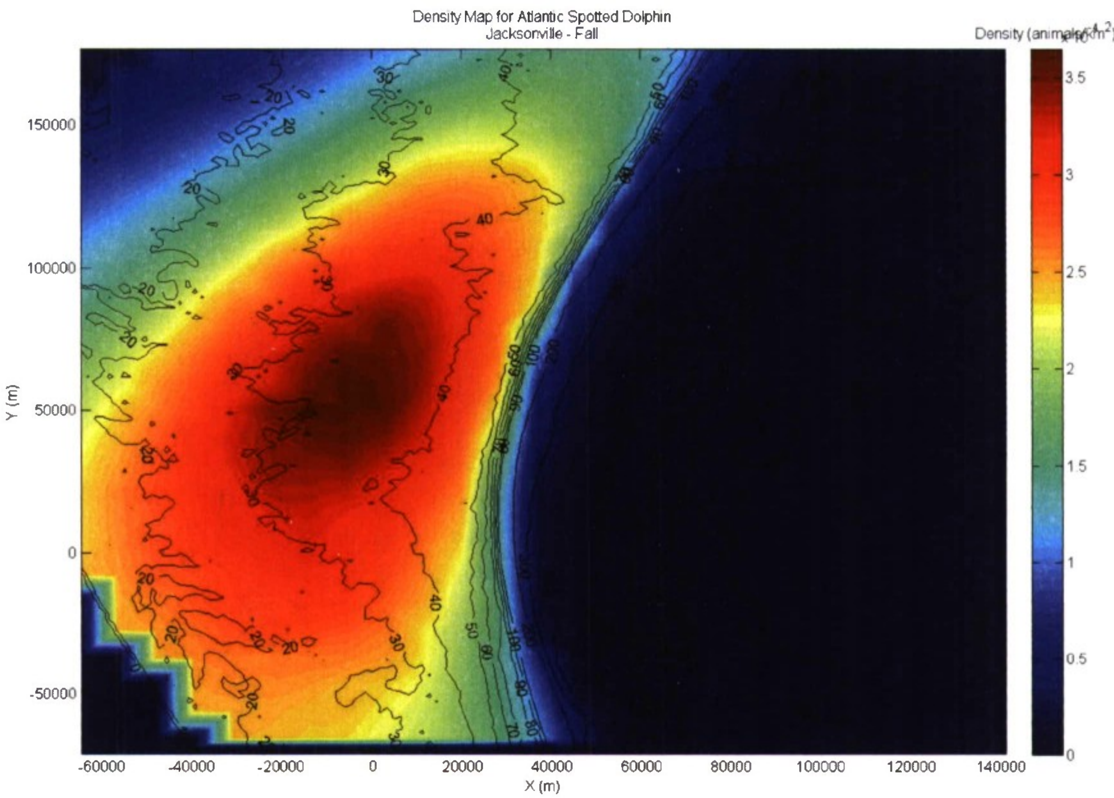

Figure 2-1. Density Map for the Atlantic Spotted Dolphin in the Jacksonville OPAREA During the Fall Season

2.3 CAUTIONS

The marine mammal density estimate maps that were used do not include estimating bias *g(0)* (DoN, 2007a). The *g(0)* bias includes many factors, such as sightability/detectability of the animal (dive characteristics, dive interval), viewing conditions, observers, and platform characteristics. As a result, the density estimates are biased and underestimated.

3. ACOUSTIC THRESHOLDS

Only cetaceans were considered for this analysis because of a lack of significant presence of pinnipeds. The criteria presented in this section were established by a Navy panel convened by the CNO (N-45).

3.1 ACOUSTIC UNITS

The analysis unit used for determining harassment thresholds is 1 $\mu Pa^2 \cdot s$ and is designated "sound exposure level" or SEL. The equation used in the model is

$$SEL = SPL + 10\log_{10}(T), \tag{1}$$

where *SEL* is sound exposure level in dB re1 $\mu Pa^2 \cdot s$, *T* is the time duration of the signal spread in seconds, and *SPL* is the sound pressure level defined as

$$SPL = \log_{10}\left(\frac{\overline{P}}{P_{ref}}\right), \tag{2}$$

where $\overline{P}$ is the root-mean-squared (rms) sound pressure,

$$\overline{P} = \sqrt{\frac{1}{T}\int_0^T p^2(t)dt}, \tag{3}$$

and P_{ref} is the standard reference pressure (in this case, $P_{ref} = 1\ \mu Pa$). Derivation of the equation is contained in appendix C of the USWTR DEIS (DoN, 2008a).

3.2 MARINE MAMMAL HARASSMENT CRITERIA

This analysis model labels the results in terms of Level A exposures and Level B exposures and defines the terms to mean permanent threshold shift (PTS) and TTS, respectively. The CNO (N-45) provided the criteria for onset-PTS and onset-TTS, which are derived in the USWTR DEIS (DoN, 2008a). Since data for onset-PTS are not available, terrestrial mammal data were used to determine a relationship between onset-TTS and onset-PTS. "The onset-PTS threshold is based on a 20-dB re 1 µPa-increase in SEL over that required for onset-TTS" (DoN, 2008a). Thus,

$$\text{Level B Harassment (onset-TTS)} = 195 \text{ to } 215\ \text{dB}//1\ \mu Pa^2 \cdot s, \tag{4}$$

and

$$\text{Level A Harassment (onset-PTS)} = \text{onset TTS} + 20 \text{ dB re } 1\ \mu\text{Pa} = 215 \text{ dB//1 } \mu\text{Pa}^2\cdot\text{s}. \quad (5)$$

These criteria provide acoustic thresholds for determining physical changes, either temporary or permanent, in a marine mammal. Another issue involves behavioral disturbances where a mammal's normal behavior is disturbed, but the mammal does not suffer a physical auditory change. This type of disturbance is also termed "Level B harassment."

3.3 SUMMARY OF SCIENTIFIC EVIDENCE RELEVANT TO ASSESSING BEHAVIORAL EFFECTS

3.3.1 Background

Based on available evidence, marine animals are likely to exhibit any of a suite of potential behavioral responses or combinations of behavioral responses upon exposure to sonar transmissions. Potential behavioral responses include, but are not limited to, avoiding exposure or continued exposure, behavioral disturbance (including distress or disruption of social or foraging activity), habituation to the sound, becoming sensitized to the sound, or not responding to the sound.

Existing studies of behavioral effects of human-made sounds in marine environments remain inconclusive partly because many of those studies (1) have lacked adequate controls, (2) applied to only certain kinds of exposures (which are often different from the exposures being analyzed in the study), and (3) had limited ability to detect behavioral changes that may be significant to the biology of the animals being observed. These studies are further complicated by the variety of behavioral responses that marine mammals exhibit and how those responses can vary substantially by species, individuals, and the context of an exposure. In some circumstances, some individuals will continue normal behavioral activities in the presence of high levels of human-made noise. In other circumstances, the same individual or other individuals may avoid an acoustic source at much lower received levels (Richardson et al., 1995a; Wartzok et al., 2003; Southall et al., 2007). These differences within and between individuals appear to result from a complex interaction of experience, motivation, and learning that are difficult to quantify and predict.

It is possible that some marine mammal behavioral reactions to anthropogenic sound may result in strandings. Several "mass stranding" events—strandings that involve two or more individuals of the same species (excluding a single cow–calf pair)—that have occurred over the past two decades have been associated with naval operations, seismic surveys, and other anthropogenic activities that introduced sound into the marine environment. Sonar exposure has been identified as a contributing cause or factor in five specific mass stranding events: Greece in 1996, Bahamas in March 2000, Portugal in 2000, Canary Islands in 2002, and Spain in 2006 (Advisory Committee Report on Acoustic Impacts on Marine Mammals, 2006). In these circumstances, exposure to acoustic energy has been considered a potential indirect cause of the death of marine mammals (Cox et al., 2006). A popular hypothesis regarding a potential cause of the strandings is that tissue damage results from a "gas and fat embolic syndrome" (Fernandez

et al., 2005; Jepson et al., 2003; Jepson et al., 2005). Models of nitrogen saturation in diving marine mammals have been used to suggest that altered dive behavior might result in the accumulation of nitrogen gas, thus creating the potential for increased nitrogen bubble formation (Houser et al., 2001; Zimmer and Tyack, 2007). If so, this mechanism might explain the findings of gas and bubble emboli in stranded beaked whales. It is also possible that stranding is a behavioral response to a sound under certain contextual conditions and that the subsequently observed physiological effects of the strandings (for example, overheating, decomposition, or internal hemorrhaging from being on shore) were the result of the stranding and not the direct result of exposure to sonar (Cox et al., 2006).

3.3.2 Risk Function Adapted from Feller (1968)

The particular acoustic risk function developed by the Navy and the National Marine Fisheries Service (NMFS) estimates the probability of behavioral responses that the NMFS would classify as harassment for the purposes of the MMPA given exposure to specific received levels of MFA sonar. The mathematical function is derived from a solution by Feller (1968) for the probability as defined in "Final Overseas Environmental Impact Statement and Environmental Impact Statement for Surveillance Towed Array Sensor System Low-Frequency Active (SURTASS LFA) Sonar" (DoN, 2001). The same mathematical function was used in "Final Supplemental Environmental Impact Statement for Surveillance Towed Array Sensor System Low-Frequency Active (SURTASS LFA) Sonar" (DoN, 2007c) for the probability of mid-frequency active (MFA) sonar risk for MMPA Level B behavioral harassment with input parameters modified by NMFS for MFA sonar for mysticetes, odontocetes, and pinnipeds.

To represent a probability of risk, the function should have a value near 0 at very low exposures and a value near 1 for very high exposures. One class of functions that satisfies this criterion is cumulative probability distributions. In selecting a particular functional expression for risk, several criteria were identified:

1. The function must use parameters to focus discussion on areas of uncertainty.

2. The function should contain a limited number of parameters.

3. The function should be capable of accurately fitting experimental data.

4. The function should be reasonably convenient for algebraic manipulations.

The following mathematical function is that which was adapted from a solution in Feller (1968) and described in the DoN SURTASS LFA sonar final OEIS/EIS (DoN, 2001):

$$R = \frac{1-\left(\dfrac{L-B}{K}\right)^{-A}}{1-\left(\dfrac{L-B}{K}\right)^{-2A}}, \tag{6}$$

where

R = risk (0 – 1.0);

L = reeeived level (RL) in dB re 1 μPa;

B = basement RL in dB re 1 μPa. (120 dB re 1 μPa);

K = the RL inerement above basement in dB at whieh there is 50% risk;

A = risk transition sharpness paramcter (A = 10 odontocetes (cxeept harbor porpoises)/pinnipeds; A = 8 mystieetes) (explained in seetion 4.3.3.1.5 of the USWTR DEIS (DoN, 2008a)).

To use this funetion, the values of the three parameters (B, K, and A) must be established. As further explained in seetion 4.3.3.1.3 of the DEIS (DoN, 2008a), the values used in this analysis are based on three sources of data: (1) TTS experiments conducted at SPAWAR Systems Center (SSC), San Diego, and documented in Finneran et al. (2001, 2003, and 2005) and in Finneran and Sehlundt (2004); (2) reeonstruetion of sound fields produeed by the USS *Shoup* assoeiated with the behavioral responses of killer whales observed in Haro Strait and documented in reports by the National Marine Fisheries Service (2005), DoN (2004), and Fromm (2004a, 2004b); and (3) observations of the behavioral response of North Atlantic right whales exposed to alcrt stimuli containing midfrequency eomponents documented in Nowaeek et al. (2004). The input parameters, as defined by the NMFS (2005), are based on very limited data that represent the best available seienec at this time.

3.3.3 Data Sources Used for Risk Function

There is widespread eonsensus that cetaeean response to MFA sound signals must be better defined, using controlled cxperiments (Cox et al., 2006; Southall et al., 2007). The Navy is contributing to an ongoing behavioral responsc study in the Bahamas; it is hoped that this study will provide some initial information on beaked whales—the speeies identified as the most sensitive to MFA sonar. The NMFS is leading this international effort with scientists from various aeademie institutions and research organizations to conduct studies on how marine mammals respond to underwater sound exposures.

Until additional data are available, the NMFS and the Navy have determined that the following three datasets are most applicable for the direct use in developing risk function paramcters for MFA sonar: (1) data from SSC's controlled expcriments, (2) data from studies of baleen (mysticetes) whale responses, and (3) observations of killer whales in Haro Strait. These datasets represent the only known data that specifically relate altered bchavioral responses to exposure to MFA sound sources. Until applicable datasets are evaluated to better qualify harassment from high-frequency array (HFA) sourees, the risk function derived for MFA sourees will apply to HFA.

3.3.3.1. Data from SSC's Controlled Experiments. Most of the observations of the behavioral responses of toothed whales are the results of a series of controlled experiments on bottlenose dolphins and beluga whales conducted by researchers at the SSC San Diego (Finneran et al., 2001, 2003, 2005; Finneran and Schlundt, 2004; Schlundt et al., 2000), whose findings are summarized in the following paragraphs. In experimental trials with marine mammals trained to perform tasks when prompted, scientists evaluated whether the marine mammals performed these tasks when they were exposed to midfrequency tones. Altered behavior during experimental trials usually involved refusal of animals to return to the site of the sound stimulus. This refusal included what appeared to be deliberate attempts to avoid a sound exposure or to avoid the location of the exposure site during subsequent tests (Schlundt et al., 2000, Finneran et al., 2002). Bottlenose dolphins exposed to 1-sec intense tones exhibited short-term changes in behavior above received sound levels of 178 to 193 dB re 1 μPa rms, and beluga whales did so at received levels of 180 to 196 dB and above. Test animals sometimes vocalized after an exposure to impulsive sound from a seismic water gun (Finneran et al., 2002). In some instances, animals exhibited aggressive behavior toward the test apparatus (Ridgway et al., 1997; Schlundt et al., 2000).

1. Finneran and Schlundt (2004) – In this report, Finneran and Schlundt examined behavioral observations recorded by the trainers or test coordinators during the experiments conducted by Schlundt et al. (2000) and Finneran et al. (2001, 2003, 2005) that featured 1-sec tones. These included observations from 193 exposure sessions (fatiguing stimulus level > 141 dB re 1 μPa) conducted by Schlundt et al. (2000) and 21 exposure sessions conducted by Finneran et al. (2001, 2003, 2005). The observations were made during exposures to sound sources at 0.4 kHz, 3 kHz, 10 kHz, 20 kHz, and 75 kHz. The TTS experiments that supported Finneran and Schlundt (2004) are further explained below:

2. Schlundt et al. (2000) – This report provides a detailed summary of the behavioral responses of trained marine mammals during TTS tests conducted at SSC San Diego with 1-sec tones. Schlundt et al. (2000) reported eight individual TTS experiments. Fatiguing stimuli durations were 1 sec; exposure frequencies were 0.4 kHz, 3 kHz, 10 kHz, 20 kHz, and 75 kHz. The experiments were conducted in San Diego Bay. Because of the variable ambient noise in the bay, low-level broadband masking noise was used to keep hearing thresholds consistent. Schlundt et al. (2000) reported that "behavioral alterations," or deviations from the behaviors that the animals being tested had been trained to exhibit, occurred as the animals were exposed to increasing fatiguing stimulus levels.

3. Finneran et al. (2001, 2003, 2005) – This documentation describes TTS experiments that were conducted using tones at 3 kHz. The test method was similar to that of Schlundt et al. (2000) except that the tests were conducted in a pool with a very low ambient noise level (below 50 dB re 1 $\mu Pa^2/Hz$) and no masking noise was used. Two separate experiments were conducted using 1-sec tones. In the first experiment, fatiguing sound levels were increased from 160 to 201 dB sound pressure level (SPL). In the second experiment, fatiguing sound levels between 180 and 200 dB SPL were randomly presented.

*3.3.3.2 **Data from Studies of Baleen (Mysticetes) Whale Responses.*** The only mysticete data available resulted from field experiments in which baleen whales (mysticetes) were exposed to sounds ranging in frequency from 50 Hz (ship noise playback) to 4500 Hz (alert stimulus) (Nowacek et al., 2004). Behavioral reactions to an alert stimulus, consisting of a combination of tones and frequency and amplitude-modulated signals ranging in frequency from 500 Hz to 4500 Hz, were the only portion of the study used to support the risk function input parameters.

Nowacek et al. (2004, 2007) – This report consists of documented observations of the behavioral response of North Atlantic right whales exposed to alert stimuli containing midfrequency components. To assess risk factors involved in ship strikes, a multisensor acoustic tag was used to (1) measure the responses of whales to passing ships and (2) test their responses to controlled sound exposures, which included recordings of ship noise, the social sounds of conspecifics, and a signal designed to alert the whales.

The alert signal was 18 minutes of exposure consisting of three 2-minute signals played sequentially three times over. The three signals had a 60% duty cycle and consisted of (1) alternating 1-sec pure tones at 500 Hz and 850 Hz; (2) a 2-sec logarithmic down-sweep from 4500 Hz to 500 Hz; and (3) a pair of low (1500 Hz)-high (2000 Hz) sine wave tones amplitude modulated at 120 Hz, each for 1-sec. The purposes of the alert signal were to (1) provoke an action from the whales via the auditory system with disharmonic signals that cover the whales' estimated hearing range, (2) maximize the signal-to-noise ratio (obtain the largest difference between background noise), and (3) provide localization cues for the whale. Five out of six whales reacted to the signal designed to elicit such behavior. Maximum received levels ranged from 133 to 148 dB re 1 $\mu Pa/\sqrt{Hz}$.

*3.3.3.3 **Observations of Killer Whales in Haro Strait in the Wild.*** In May 2003, killer whales (*Orcinus orca*) were observed exhibiting behavioral responses while *Shoup* was engaged in MFA sonar operations in the Haro Strait in the vicinity of Puget Sound, WA. Although these observations were made in an uncontrolled environment, the sound field associated with the sonar operations had to be estimated, and the behavioral observations were reported for groups of whales, not individual whales, the observations associated with the *Shoup* provide the only available dataset of the behavioral responses of a wild, non-captive animal upon exposure to the AN/SQS-53 MFA sonar.

National Marine Fisheries (2005), DoN (2004), Fromm (2004a, 2004b) – These reports document the reconstruction of sound fields produced by the *Shoup* associated with the behavioral response of killer whales observed in Haro Strait. This reconstruction included an estimate of 169.3 dB SPL, which represents the mean received level at a point of closest approach within a 500-m-wide area in which the animals were exposed. Within that area, the estimated received levels varied from approximately 150 to 180 dB SPL.

3.3.4 Limitations of the Risk Function Data Sources

Any risk function derived to estimate the probability of marine mammal behavioral responses has substantial limitations and challenges—largely attributable to sparse data. Ideally, there should be multiple functions for different marine mammal taxonomic groups. Current data are insufficient to support risk functions for various groups. The goal is to base risk functions on empirical measurement.

The risk function presented here is based on three datasets that NMFS and Navy have determined to be the best available science at this time. The Navy and NMFS acknowledge that each of these datasets has limitations.

While NMFS considers all datasets as being weighted equally in the development of the risk function, the Navy believes that the SSC San Diego data are the most rigorous and applicable for the following reasons:

1. The data represent the only source of information where the researchers had complete control over and ability to quantify the noise exposure conditions.

2. The altered behaviors were identifiable because of long-term observations of the animals.

3. The fatiguing noise consisted of tonal exposures with limited frequencies contained in the MFA sonar bandwidth.

The Navy and NMFS, however, agree that the three datasets used as the basis of the risk function have the following limitations:

1. The three datasets represent the responses of only four species: trained bottlenose dolphins and beluga whales, North Atlantic right whales in the wild, and killer whales in the wild.

2. None of the three datasets represents experiments designed for behavioral observations of animals exposed to MFA sonar.

3. The behavioral responses of marine mammals that were observed in the wild are based solely on an estimated received level of sound exposure. These responses do not consider (because of minimal or no supporting data) (1) potential relationships between acoustic exposures and specific behavioral activities (for example, feeding, reproduction, changes in diving behavior), variables such as bathymetry, or acoustic waveguides; or (2) differences in individuals, populations, or species, or the prior experiences, reproductive state, hearing sensitivity, or age of the marine mammal.

3.3.4.1 SSC San Diego Trained Bottlenose Dolphins and Beluga Dataset. This dataset has the following limitations:

1. The animals were trained animals in captivity; therefore, they may be more or less sensitive than cetaceans found in the wild (Domjan, 1998).

2. The tests were designed to measure TTS, not behavior.

3. Because the tests were designed to measure TTS, the animals were exposed to much higher levels of sound than the baseline risk function (only two of the 193 observations were at levels below 160 dB re 1 μPa2-s).

4. The animals were exposed in a shallow bay or pool rather than the open ocean.

5. The tones used in the tests were 1-sec pure tones similar to MFA sonar.

3.3.4.2 North Atlantic Right Whales in the Wild Dataset. This dataset has the following limitations:

1. The observations of behavioral response were from exposure to alert stimuli that contained midfrequency components but were not similar to an MFA sonar ping. The alert signal was 18 minutes of exposure consisting of three 2-minute signals played sequentially three times over. The three signals had a 60% duty cycle and consisted of (1) alternating 1-sec pure tones at 500 Hz and 850 Hz, (2) a 2-sec logarithmic down-sweep from 4500 Hz to 500 Hz, and (3) a pair of low (1500 Hz)-high (2000 Hz) sine wave tones amplitude-modulated at 120 Hz, each 1-sec long. These 18-minute alert stimuli are in contrast to the average 1-sec ping every 30 seconds in a comparatively very narrow frequency band used by military sonar.

2. The purpose of the alert signal was, in part, to provoke an action from the whales through an auditory stimulus.

3.3.4.3 Killer Whales in the Wild Dataset. This dataset has the following limitations:

1. The observations of behavioral harassment were complicated because there were other sources of harassment in the vicinity (other vessels and their interaction with the animals during the observation).

2. The observations were anecdotal and inconsistent. There were no controls during the observation period, resulting in no way to assess the relative magnitude of the observed response as opposed to baseline conditions.

3.3.5 Input Parameters for the Feller-Adapted Risk Function

The values of B, K, and A must be specified to utilize the risk function defined in section 4.3.3.1.2 of the USWTR DEIS (2008a). The risk continuum function approximates the dose-response function in a manner analogous to pharmacological risk assessment (DoN, 2001). In this case, the risk function is combined with the distribution of SELs to estimate aggregate impact on an exposed population.

3.3.5.1 Basement Value for Risk—B Parameter. The B parameter defines the basement value for risk, below which the risk is so low that calculations are impractical. This 120-dB level is taken as the estimate RL, below which the risk of significant change in a biologically important behavior approaches zero for the MFA sonar risk assessment. This level is (1) based on a broad overview of the levels at which multiple species have been reported responding to a variety of sound sources, both midfrequency and other, (2) was recommended by the scientists, and (3) has been used in other publications. The Navy recognizes that for actual risk of changes in behavior to be zero, the signal-to-noise ratio of the animal must also be zero.

3.3.5.2 K Parameter. The NMFS and the Navy used the mean of the following values to define the midpoint of the function: (1) the mean of the lowest RLs (185.3 dB) at which individuals responded with altered behavior to 3-kHz tones in the SSC dataset; (2) the estimated mean RL value of 169.3 dB produced by the reconstruction of the *Shoup* incident in which killer whales were exposed to MFA sonar (range modeled possible RLs of 150 to 180 dB); and (3) the mean of the five maximum RLs, which is 139.2 dB SPL (the responses of right whales to the alert stimuli were significantly altered compared to their responses to the control (no input signal) Nowacek et al. (2004). The arithmetic mean of these three mean values is 165 dB SPL. The value of K is the difference between the value of B (120 dB SPL) and the 50% value of 165 dB SPL; therefore, K = 45.

3.3.5.3 Risk Transition—A Parameter. The A parameter controls how rapidly risk transitions from low to high values with increasing RL. As A increases, the slope of the risk function increases. For very large values of A, the risk function can approximate a threshold response or step function. The NMFS has recommended that the Navy use A = 10 as the value for odontocetes (except harbor porpoises) and pinnipeds (see figure 3-1), and A = 8 for mysticetes (see figure 3-2) (NMFS, 2008).

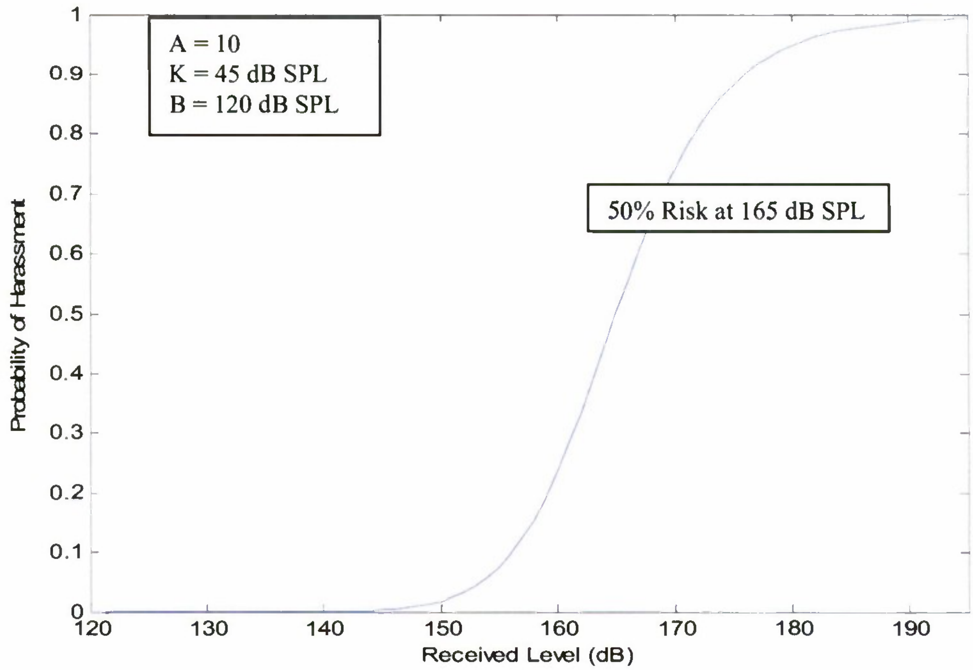

Figure 3-1. Risk Function Curve for Odontocetes (Toothed Whales, Except Harbor Porpoises) and Pinnipeds

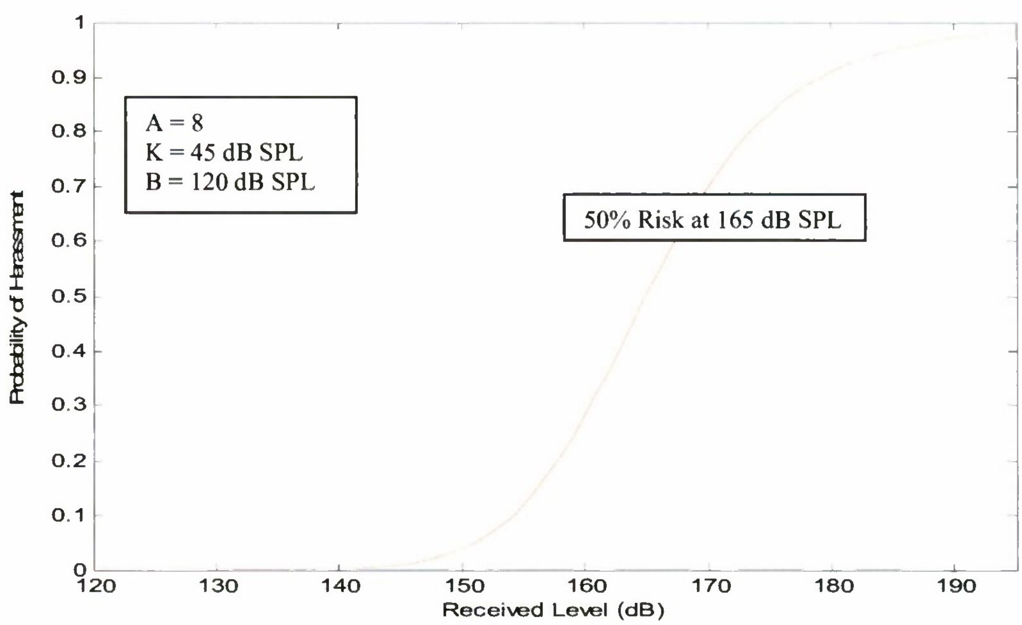

Figure 3-2. Risk Function Curve for Mysticetes (Baleen Whales)

3.3.5.3.1 Justification for the Steepness Parameter of A = 10 for the Odontocete Curve. The NMFS independent review process described in the Hawaii Range Complex final EIS/OEIS (DoN, 2008b) provided the impetus for the selection of the parameters for the risk function curves. One scientist recommended staying close to the risk continuum concept as used in the SURTASS LFA sonar EIS (DoN, 2007c). This scientist opined that both the basement and slope values, B = 120 dB and A = 10, respectively, from the SURTASS LFA sonar risk continuum concept are logical solutions in the absence of compelling data to select alternate values supporting the Feller-adapted risk function for MFA sonar. Another scientist indicated that a steepness parameter had to be selected, but did not recommend a value. Four scientists did not specifically address the selection of a slope value. After reviewing the six scientists' recommendations, the two NMFS scientists recommended selection of A = 10. Direction was provided by the NMFS to use the A = 10 curve for odontocetes based on the scientific review of potential risk functions explained in section 4.1.2.4.9.2 of the Hawaii Range Complex final EIS/OEIS (DoN, 2008b).

As background, a sensitivity analysis of the A = 10 parameter was undertaken and presented in appendix D of the SURTASS/LFA FEIS (DoN, 2001). The analysis was performed to support the A = 10 parameter for mysticete whales responding to a low-frequency sound source, a frequency range to which the mysticete whales are thought to be most sensitive. The sensitivity analysis results confirmed the increased risk estimate for animals exposed to sound levels below 165 dB. Results from the Low-Frequency Sound Scientific Research Program (LFS SRP) phase II research showed that whales (gray whales in this case) did scale their responses with RL as supported by the A = 10 parameter (Buck and Tyack, 2000). In the second phase of the LFS SRP research, migrating gray whales showed responses similar to those observed in earlier research (Malme et al., 1984) when the low-frequency (LF) source was moored in the migration corridor (2 km (1.1 nmi) from shore). The study extended those results with confirmation that a louder source level (SL) elicited a larger scale avoidance response; however, when the source was placed offshore (4 km (2.2 nmi) from shore) of the migration corridor, the avoidance response was not evident. This result implies that the inshore avoidance model, in which 50% of the whales avoid exposure to levels of 141 $\pm$3 dB, may not be valid for whales in proximity to an offshore source (DoN, 2001). As concluded in the SURTASS LFA sonar final OEIS/EIS (DoN, 2001), the value of A = 10 produces a curve that has a more gradual transition than the curves developed by the analyses of migratory gray whale studies (Malme et al., 1984; Buck and Tyack, 2000); and SURTASS LFA sonar final OEIS/EIS, 2001; and NMFS, 2008).

3.3.5.3.2 Justification for the Steepness Parameter of A = 8 for the Mysticete Curve. The study conducted by Nowacek and others (Nowacek et al., 2004) provides the only available data source for a mysticete species behaviorally responding to a sound source (that is, alert stimuli) with frequencies in the range of tactical mid-frequency (MF) sonar (1 – 10 kHz), including empirical measurements of RLs. While there are fundamental differences in the stimulus used by Nowacek et al. (2004) and tactical mid-frequency sonar (for example, SL, waveform, duration, directionality, likely range from source to receiver), they are generally similar in frequency band and the presence of modulation patterns. Thus, while they must be considered with caution in interpreting behavioral responses of mysticetes to MF sonar, they seemingly cannot be excluded from this consideration, given the overwhelming lack of other information. The Nowacek et al.

(2004) data indicate that five out of the six North Atlantic right whales exposed to an alert stimuli "significantly altered their regular behavior and did so in identical fashion" (that is, stopped feeding and swam to just under the surface). For these five whales, maximum RLs associated with this response ranged from rms pressure levels of 133 – 148 dB (re: 1 μPa).

When six scientists (one of whom was Nowacek) were asked to independently evaluate available data for constructing a dose response curve based on a solution adapted from Feller (1968), four of them, including Nowacek, indicated that the Nowacek et al. (2004) data were appropriate and necessary to consider in the analysis. While other parameters associated with the solution adapted from Feller (1968) were provided by many of the scientists (that is, basement parameter (B) and increment above basement where there is 50% risk (K)), only one scientist provided a suggestion for the risk transition parameter A.

A single curve may provide the simplest quantitative solution for estimating behavioral harassment. The NMFS-OPR decision to adjust the risk transition parameter from A = 10 to A = 8 for mysticetes and to create a separate curve for mysticetes was based on the fact that using the shallower slope better reflected the increased risk of behavioral response at relatively low RLs suggested by the Nowacek et al. (2004) data. Specifically, reducing the risk transition parameter from 10 to 8 reduces the slope of the curve for mysticetes—increasing the proportion of the population being classified as behaviorally harassed at lower RLs. The adjusted risk parameter also slightly reduces the estimate of behavioral response probability at very high RLs, which is expected to have little practical effect because of the very limited probability of exposures well above the midpoint of the function. This adjustment allows for a slightly more conservative approach in estimating behavioral harassment at relatively low RLs for mysticetes compared to the odontocete curve and is supported by the only dataset currently available.

Note that the current approach (A = 8) yields an extremely low probability for behavioral responses at RLs between 133 – 148 dB—where the Nowacek data indicated significant responses in a majority of whales studied. Although creating an entire curve for mysticetes based strictly on the Nowacek et al. (2004) data was advocated by several of the reviewers, doing so was considered inappropriate by the NMFS-Office of Protected Resources (OPR) for two reasons: (1) the sound source used in this study was not identical to tactical MF sonar, and (2) there were only five data points available. The policy adjustment made by NMFS-OPR was also intended to capture some of the additional recommendations and considerations provided by the scientific panel (that is, the curve should be more data driven and that a greater probability of risk at lower RLs be associated with direct application of the data collected by Nowacek et al. (2004).

3.3.6 Basic Application of the Risk Function and Relation to the Current Regulatory Scheme

The risk function is used to estimate the percentage of an exposed population that is likely to exhibit behaviors that would qualify as harassment (as that term is defined by the MMPA applicable to military readiness activities, such as the Navy's testing and training with MFA sonar) at a given RL of sound. Figure 3-3 illustrates this relationship for a representative marine animal. Between 160 and 170 dB SPL (dB re: 1 μPa rms), the risk (or probability) of

harassment is defined according to this function as 50%; the Navy/NMFS applies that by estimating that 50% of the individuals exposed at that RL are likely to respond by exhibiting behavior that NMFS would classify as behavioral harassment. The risk function is not applied to individual animals, only to exposed populations.

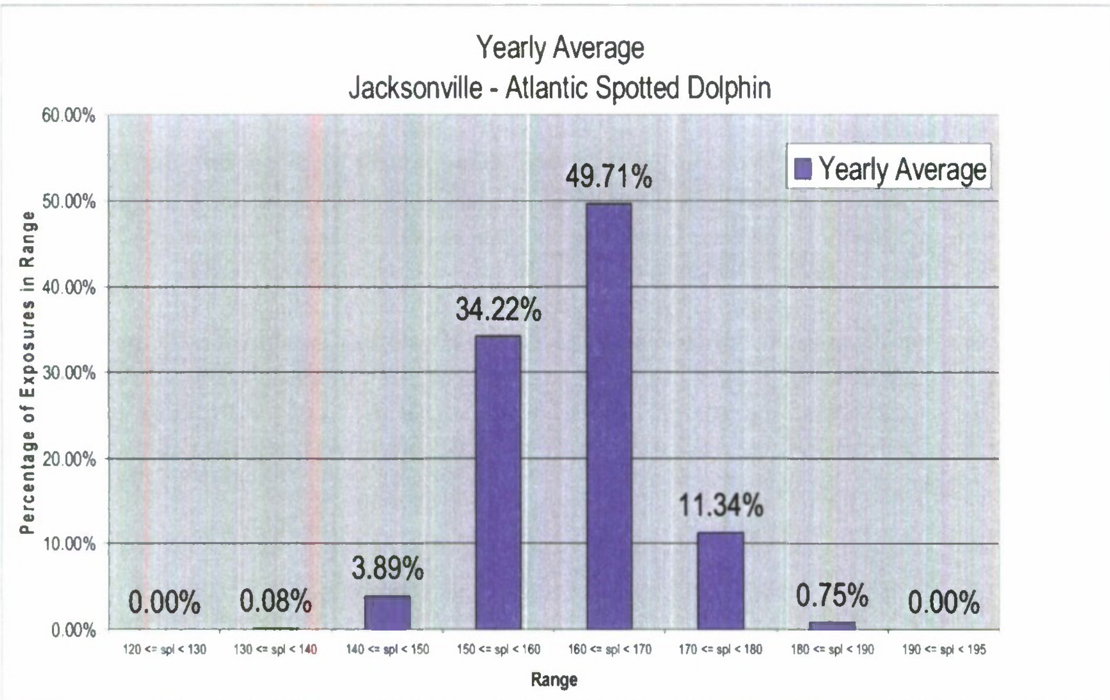

Figure 3-3. Percentage of Exposures Exhibiting Behavioral Harassments Resulting from the Risk Function

The data used to produce the risk function were compiled from four species that had been exposed to sound sources in a variety of different circumstances. As a result, the risk function represents a general relationship between acoustic exposures and behavioral responses that is then applied to specific circumstances. The risk function represents a relationship that is deemed to be generally true, based on the limited, best-available science, but may not be true in specific circumstances.

In particular, the risk function, as currently derived, treats the RL as the only variable that is relevant to a marine mammal's behavioral response. However, we know that many other variables—the marine mammal's gender, age, and prior experience; the activity it is engaged in during an exposure event; its distance from a sound source; the number of sound sources; and whether the sound sources are approaching or moving away from the animal—can be critically important in determining whether and how a marine mammal will respond to a sound source (Southall et al., 2007). The data that are currently available do not allow for the incorporation of these other variables in the current risk functions; however, the risk function represents the best use of the data that are available.

The DoN and NMFS applied the MFA risk function curve to HFA sources because of the lack of available and complete information regarding HFA sources. As more specific and applicable data become available for MFA/HFA sources, NMFS can use these data to modify the outputs generated by the risk function to make them more realistic. Ultimately, data may exist to justify the use of additional, alternate, or multivariate functions. As mentioned, it is known that the distance from the sound source and whether the sound source is perceived as approaching or moving away can affect the way an animal responds to a sound (Wartzok et al., 2003).

In the Hawaii Range Complex (HRC) example, animals exposed to RLs between 120 and 130 dB may be more than 65 nmi (131,651 yards) from a sound source; those distances would influence whether those animals might perceive the sound source as a potential threat, and would influence their behavioral responses to that threat. Though there are data showing marine mammal responses to sound sources at that RL, the NMFS does not currently have any data that describe the response of marine mammals to sounds at that distance (or to other contextual aspects of the exposure, such as the presence of higher frequency harmonics), much less data that compare responses to similar sound levels at varying distances. If data, however, become available that suggest animals are less likely to respond (in a manner NMFS would classify as harassment) to certain levels beyond certain distances, or that they are more likely to respond at certain closer distances, the Navy will re-evaluate the risk function in an effort to incorporate any additional variables into the "take" estimates.

Last, pursuant to the MMPA, an applicant is required to estimate the number of animals that will be "taken" by their activities. The amount of takes factors into the type of analysis that the NMFS must perform to determine whether the activity will have a "negligible impact" on the species or stock. Level B (behavioral) harassment occurs at the level of the individual(s) and does not assume any resulting population-level consequences, though there are known avenues through which behavioral disturbance of individuals can result in population-level effects. Alternately, a negligible impact finding is based on the lack of likely adverse effects on annual rates of recruitment or survival (that is, population-level effects).

An estimate of the number of Level B harassment takes alone is not enough information on which to base an impact determination. In addition to considering estimates of the number of marine mammals that might be "taken" through harassment, the NMFS must consider other factors, such as the nature of any responses (for example, their intensity and duration), the context of any responses (for example, critical reproductive time or location, migration), or any of the other variables (if known) already mentioned, as well as the number and nature of estimated Level A takes, the number of estimated mortalities, and effects on habitat. The Navy and the NMFS anticipate more severe effects from takes resulting from exposure to higher RLs (though there is no strict linear relationship throughout species, individuals, or circumstances) and less severe effects from takes resulting from exposure to lower RLs.

3.3.7 Specific Consideration for Harbor Porpoises

The information currently available regarding harbor porpoises, inshore species that inhabit shallow and coastal waters, suggests a very low threshold level of response for both

captive and wild animals. Threshold levels at which both captive (see Kastelein et al., 2000, 2005, 2006) and wild harbor porpoises (see Johnston, 2002) responded to sound (for example, acoustic harassment devices (ADHs), acoustic deterrent devices (ADDs), or other non-pulsed sound sources) is very low (~120 dB SPL), although the biological significance of the disturbance is uncertain. The Navy, therefore, will not use the risk function curve as presented, but it will apply a step function threshold of a 120-dB SPL estimate take of harbor porpoises (that is, the Navy assumes that all harbor porpoises exposed to 120 dB re 1 μPa or higher MFAs/HFAs will respond in a way that the NMFS considers behavioral harassment).

3.3.8 Navy Post-Acoustic Modeling Analysis

The quantification of the acoustic modeling results includes additional analysis to increase the accuracy of the number of marine mammals affected. Table 3-1 summarizes the modeling protocols used in this analysis. Post-modeling analysis includes (1) reducing acoustic footprints where they encounter land masses, (2) accounting for acoustic footprints for sonar sources that overlap to accurately sum the total area when multiple ships are operating together, and (3) better accounting for the maximum number of individuals of a species that could potentially be exposed to sonar within the course of 1 day or a discreet continuous sonar event.

Table 3-1. Navy Protocols for Accurate Modeling Quantification of Marine Mammal Exposures

Historical Data	Sonar Positional Reporting System (SPORTS)	As USWTR will be a new training range, historical usage of the area is not applicable.
Acoustic Parameters	AN/SQS-53 and AN/SQS-56	The AN/SQS-53 and AN/SQS-56 active sonar sources used separately to account for differences in source level, frequency, and exposure effects.
	Submarine Sonar	Submarine active sonar use is included in effects analysis calculations using the SPORTS database.
Post-Modeling Analysis	Land Shadow	Land shadow was determined not to affect the modeling results and was not included because of the distance from shore to the site location.
	Multiple Ships	The effect of multiple ships was not considered because of the limited occurrences where two or more ships are using active sonar simultaneously in USWTR scenarios; therefore, the effect on modeled exposure numbers is negligible.
	Multiple Exposures	Accurate accounting for training events within the course of 1 day or a discreet, continuous sonar event: • Scenario 1 (Air Undersea Warfare) – 2 hr • Scenario 2 (Surface Ship Undersea Warfare) – 3 hr • Scenario 3 (Submarine Undersea Warfare) – 6 hr • Scenario 4 (Battle Group Exercise) – 3 hr

4. ACOUSTIC SOURCE DESCRIPTIONS AND TRAINING SCENARIOS

Only antisubmarine warfare (ASW) training exercises are currently planned for the USWTR. Four ASW exercise scenarios are addressed in this analysis to capture the scope of operations on the range. This section identifies the active acoustic systems associated with each platform (aircraft, ships, submarines, etc.), describes the four training scenarios, explains the criteria for selecting active sources included in the analysis, and describes the operating parameters for each selected source to the extent that classification restrictions allow. These descriptions of training participants, acoustic sources, scenarios, yearly scenario frequency, and operating parameters fully characterize how active sonar systems are used on the range.

4.1 ACTIVE ACOUSTIC SOURCES

Each range user has or deploys active acoustic devices with varying acoustic outputs that may or may not affect the local marine mammal population. The acoustic sources that would be used at the ranges to conduct training exercises are described in the following subsections.

4.1.1 Surface Ship Sonars

1. AN/SQS-26CX – is a hull-mounted passive and active sonar system. The sonar operates in multiple active modes for optimum mission effectiveness.

2. AN/SQS-53A/B/C – is an advanced hull-mounted surface ship ASW sonar in the U.S. Navy's inventory; it can detect, identify, and track multiple targets. The sonar operates in multiple active modes for optimum mission effectiveness.

3. AN/SQS-56 – is a hull-mounted direct-path sonar used on the *Oliver Hazard Perry*–class ships.

4.1.2 Surface Ship Fathometers

The surface ship fathometer measures the depth of water from the ship's keel to the ocean floor for safe operational navigation.

4.1.3 Submarine Sonars

1. AN/BQQ-5 – is the current U.S. Navy standard submarine sonar suite. The basic AN/BQQ-5 consists of a sonar transmitting and receiving sphere and towed passive arrays. The AN/BSY-1 active system is comparable to the AN/BQQ-5. These two systems are most prevalent in the submarine fleet.

2. AN/BQQ-10 – The acoustic capability of this sonar is analogous to the AN/BQQ-5. The major difference lies in improved processing capabilities; therefore, it was not separately analyzed.

3. AN/BSY-1 (V) – is an integrated system for the mid-frequency, bow-mounted submarine active detection sonar (SADS) system and the high-frequency active mine/ice detection and avoidance system (MIDAS) mounted on the sail.

4. AN/BSY-2 – is the combat system for *Seawolf*-class submarines; its design is based on the AN/BSY-1(V). The major system sensors are a large spherical array (LSA), a low-frequency bow array (LFBA), an active hemispherical array (AHA) below the LFBA, an HFA in the sail, a wide-aperture array (WAA TB-16 or TB-23), and MIDAS. The AN/BSY-2 exists on only three Fleet submarines, so it was not included in the modeling.

4.1.4 Submarine Fathometers

The fathometer is used to measure the depth of water from the submarine's keel to the ocean floor for safe operational navigation.

4.1.5 Submarine Auxiliary Sonar Systems

1. AN/BQS-14/15 – is an under-ice navigation and mine-hunting sonar that operates at mid to high frequencies and employs a receiver as well as a projector. Later versions, that is, SADS, have been integrated as part of the AN/BSY-1 and -2.

2. AN/WQC-2A – is an underwater sonar communications system that has two frequency bands: mid frequency (MF) (1.45 to 3.1 kHz) and high frequency (HF) (8.3 to 11.1 kHz). The HF band will be used primarily for range communications at USWTR.

4.1.6 Aircraft Sonar Systems

Aircraft sonar systems that operate on the ranges include sonobuoys and dipping sonars. Sonobuoys may be deployed by P-3 aircraft or helicopters; dipping sonars are used only by helicopters. A sonobuoy is an expendable device for detecting underwater acoustic energy and for conducting vertical water column temperature measurements. Most sonobuoys are passive, but some can generate active acoustic signals, as well as listen passively. Dipping sonar is an active or passive sonar device lowered by cable from a helicopter to detect or maintain contact with underwater targets.

1. AN/AQS-13 Helicopter Dipping Sonar – is a long-range, active, scanning sonar that detects and maintains contact with underwater targets through a transducer lowered into the water from a hovering helicopter. The latest version is AN/AQS-13F.

2. AN/SSQ-62C Directional Command Active Sonobuoy System (DICASS) – This sonobuoy operates under direct command from ASW fixed-wing aircraft (P-3C). The system can also determine the range and bearing of a target relative to the sonobuoy's position. After water entry, the sonobuoy transmits sonar pulses (continuous waveform (CW) or linear frequency modulation (FM)) upon command from the aircraft. Echoes from the selected active signal are processed by the buoy before being transmitted to a receiving station on board the launching aircraft.

3. AN/AQS-22 Airborne Low-Frequency Sonar (ALFS) – is the U.S. Navy's dipping sonar system for the carrier-borne SH-60F and Light Airborne Multipurpose System (LAMPS) SH-2/SH-60B/R helicopters (LAMPS are flown from cruisers, destroyers, and frigates). ALFS employs deep- and shallow-water capabilities and operates at MF.

4.1.7 Torpedoes

Torpedoes are the primary ASW weapon used by surface ships, aircraft, and submarines. Active torpedoes transmit an acoustic signal to illuminate the target and use the received echoes for guidance. All torpedoes to be used at the USWTR will be inert (nonexplosive); they are the Mk 48 and Mk 48 advanced capability (ADCAP) heavyweight torpedoes and the Mk 46, Mk 50, and Mk 54 lightweight torpedoes. Exercise torpedoes (EXTORPs) are inert units (no warhead) with operating sonar and engines. Recoverable exercise torpedoes (REXTORPs) are inert training units that have no mobility or acoustic capability to seek, detect, and pursue targets.

4.1.8 Acoustic Device Countermeasures

Several types of acoustic countermeasures (CMs) are scheduled to be deployed in the USWTR, including the Acoustic Device Countermeasures (ADCs) Mk 1, Mk 2, Mk 3, and Mk 4. CM devices are submarine simulators that act as decoys to avert localization and torpedo attack. CMs may be towed or free-floating sources.

4.1.9 Anti-Torpedo Decoys (NIXIE)

An anti-torpedo decoy called NIXIE is used by surface ships when they are faced with a possible torpedo attack; it is towed astern of the ship. Typically, this device is not used for long periods.

4.1.10 Mobile Training Targets

Two types of training targets will be used at USWTR: the Mk 30 Mobile ASW Target and the Mk 39 Expendable Mobile ASW Training Target (EMATT). ASW training targets are used to simulate submarines in the absence of a submarine during an exercise. These training

targets are equipped with acoustic projectors emanating sounds to simulate submarine acoustic signatures and echo repeaters to simulate the reflection of a sonar signal from a submarine.

4.1.11 Tracking Pingers

Tracking pingers are used to track the position of underwater training platforms (global positioning system (GPS)-type systems are used to track in-air and surface platforms). The pinger generates a precise, preset acoustic signal that allows the platform on which it is installed to be tracked.

4.2 TRAINING SCENARIO DESCRIPTIONS

ASW training exercises are planned for USWTR. Four scenarios have been defined to capture the scope of activities by range users. The active acoustic systems associated with each platform are described in the following paragraphs and characterized for incorporation in the analysis.

4.2.1 ASW Exercise Scenario Descriptions

Submarines, surface ships, and aircraft conduct ASW operations against a submarine target either individually or as a coordinated force. Submarine targets can be submarines or mobile targets that simulate submarines both acoustically and dynamically. ASW operations and other training exercises are complex and highly variable. To best characterize and clarify these exercises for environmental effects analysis, the types of participating platforms and the number of occurrences expected yearly must be identified for each scenario.

4.2.1.1 Scenario 1: Air Undersea Warfare – One Aircraft Versus One Submarine. In this scenario, an aircraft flies over the range area, and the crew conducts a search for a target submarine. After the crew detects and localizes the submarine, a simulated attack is initiated. Each scenario typically involves the firing of one EXTORP, either a Mk 46 or Mk 50. Additional attack phases are conducted with simulated torpedo firings or REXTORPs.

4.2.1.2 Scenario 2: Surface Ship Undersea Warfare – One Ship with One Helicopter Versus One Submarine. In scenario 2, a ship carrying a helicopter crosses the range area and conducts a broad-area search for a target submarine. When the submarine's approximate position has been determined, the ship deploys the helicopter to localize and attack. In some exercises, the ship conducts its own close-in simulated attack. Each exercise period typically involves the firing of a Mk 46 or Mk 50 EXTORP by the ship, or the helicopter, or in some cases, both ship and helicopter. Some ships carry two helicopters, but only one of them participates in the exercise at any time. While the ship is searching for the submarine, the submarine may initiate simulated attacks against the ship.

The scenario 2 model reflects shared prosecution time and shared active sonar time between the surface ship and helicopter, with each being active approximately 50% of the time. The training exercise is modeled as two operational phases for the surface ship: a search period and a prosecution period. The surface sonar's operational characteristics are adjusted for the different modes of operation during these two periods.

4.2.1.3 Scenario 3: Submarine Undersea Warfare – One Submarine Versus Another Submarine. In scenario 3, two submarines on the range practice locating and attacking each other. If only one submarine is available for the exercise, that submarine practices attacks against a mobile submarine simulator or a range support boat, or it practices shallow-water maneuvers without an attack simulation. During this scenario, the submarine may attack the second submarine or submarine simulator by launching a Mk 48 REXTORP.

4.2.1.4 Scenario 4: Battle Group Exercise – Two Ships and Two Helicopters Versus One Submarine. Scenario 4 is the same as scenario 2, except that it has two ships and two helicopters searching for, locating, and attacking a submarine with a Mk 46 or Mk 50 torpedo. While the ships are searching for the submarine, the submarine may practice simulated attacks against the ships. As in scenario 2, the analysis reflects shared prosecution time between the surface ships and helicopters with each being active 50% of the time. Also, distributions between the search and prosecution phases of the operation for the surface sonars are incorporated in the model.

4.2.2 Number of Training Events Per Year

Each of the four training scenarios would be conducted a finite number of times each year at the USWTR (see table 4-1). The Navy also conducts broader scale exercises (joint task force exercise (JTFEX), composite training unit exercise (COMPTUEX), and independent deployer exercise (INDEX)) in its larger East Coast operations areas. In these larger exercises, some units may break off and conduct operations on the USWTR, following one of the described operational scenarios. On any given day, a training scenario may vary from the depictions in this document, but the total of all these scenarios represents the typical spectrum of training activities on the range. Scenario 4, having the greatest number of participants, represents the busiest range operation,.

Table 4-1. Annual Tally of USWTR ASW Training Scenarios

Scenario	Description	Duration (hours)	Stand-Alone Exercises	JTFEX, COMPTUEX, and INDEX	Yearly Exercise Total for USWTR
1	Air USW	2	319	36	355
2	Surface USW	3	62	0	62
3	Submarine USW	6	15	0	15
4	Battle Group Exercise	3	8	30	38

4.3 ACOUSTIC SOURCE SELECTION

Based on their acoustic characteristics, three acoustic sources were determined to be non-problematic and, therefore, not requiring further examination. Active sonar sources operating at 200 kHz or higher attenuate rapidly during propagation (approximately 30 dB re 1 μPa/km or more) while incurring additional signal spreading losses, resulting in very short propagation distances. High-frequency active sonar systems in excess of 200 kHz are, therefore, not normally analyzed; however, if a source has a high ping repetition rate and is active for an extended time period, it must be examined more closely.

Table 4-2 lists the active acoustic sources that were deemed non-problematic. Because of their operational characteristics, these sources have a negligible potential to affect marine mammals and, therefore, do not require further examination. Each source is described and not further addressed from an acoustic exposure standpoint. Some of the operating characteristics of these sources are classified and described only in general terms.

Table 4-2. Other Acoustic Sources Not Considered Further

Acoustic Source	Comment
Underwater mobile sound communications (UQC)	Source level and frequency are non-problematic but classified.
Mk 30 Target	Source level is non-problematic but classified.
Mk 39 EMATT	Source level is non-problematic but classified.

The operational characteristics of the AN/SQS-26CX sonar system are very similar to those of the AN/SQS-53C. In all modes of operation to be used on the range, either the two systems are identical or the AN/SQS-53C is a slightly worse case. Accordingly, the AN/SQS-53C was used as the representative system for the model. Because the Mk 46, Mk 50, and Mk 54 have similar acoustic characteristics, the Mk 46 was chosen as the representative lightweight torpedo for the model. Table 4-3 identifies the acoustic sources that were modeled in this exposure analysis (in each exercise scenario, the sources are employed in various combinations):

Table 4-3. Acoustic Sources Modeled

Source	Associated Platform
DICASS sonobuoys	P-3 aircraft
AN/AQS-22 (ALFS) dipping sonar	Helicopter
AN/SQS-53C	Surface ship
AN/SQS-56	Surface ship
AN/BQQ-5	Submarine
Mk 46 lightweight torpedo sonar	Submarine, surface ship, helicopter, P-3
Mk 48 ADCAP torpedo sonar	Submarine
Fathometer	Surface ship and submarine
ADCs	Submarine
Mk 84 tracking pinger	Submarine
NIXIE	Surface ship

4.4 SOURCE OPERATIONAL DESCRIPTIONS

Several parameters were defined for each of the modeled sources: center frequency, repetition rate, pulse length, SPL, horizontal and vertical beamwidth, frequency of use, mobility, and operating depths. A brief operational description of each modeled source is provided below.

Each source was modeled so that it could be applied to any of the four training scenarios. This modeling was achieved by calculating a harassment rate for the source based on either the duration of use or the specific number of times the source was used. Additionally, consistent vessel paths and common fixed positions for stationary sources facilitated the analysis. These paths and points capture a representative sample of the acoustic properties expected over the training area. Complex propagation calculations are completed for the acoustic sources either along the propagation path or at fixed positions, allowing the assessment of the effects that a scenario has on each marine mammal species. Determining the total annual exposures becomes a relatively simple series of spreadsheet-level calculations. The following subparagraphs state the assumptions made for each of the acoustic sources in the analysis.

4.4.1 DICASS Sonobuoys

DICASS sonobuoys would be employed by helicopters and P-3 patrol aircraft in scenario 1 and by helicopters in scenarios 2 and 4. DICASS sonobuoys share time with the helicopter dipping sonar. When helicopters are involved in a scenario, DICASS sonobuoys operate 50% of the time, with two DICASS buoys deployed per aircraft. The rest of the time, helicopters are assumed to employ their dipping sonar. Over the next several years, all Fleet ASW helicopters will evolve to the new SH-60R variant, which will employ either sonobuoys or dipping sonar on any given mission.

The DICASS sonobuoys were modeled as stationary sources in a set pattern. Three specific locations on the range were selected based on the range bathymetry. Two of these locations were in the shallower depth regime, and the third was in the deeper regime. Operationally, the source will be deployed at either a deep or a shallow depth. In the model, the source was deployed at a shallow depth at each of the three analysis locations in addition to being deployed at a deeper depth at the deeper location.

4.4.2 Dipping Sonar

Dipping sonar would be employed in scenarios 1, 2, and 4 by helicopters. This sonar is assumed to be employed 50% of the time that helicopters are used (for the remaining 50% of helicopter time DICASS sonobuoys are used). There are two types of dipping sonar, the AN/AQS-13 and the AN/AQS-22 ALFS. Rather than model both sonars, only the ALFS was modeled. The two dippers have similar source levels, but ALFS operates at a lower frequency and, therefore, has more potential to be problematic because there is less attenuation at low frequencies.

Dipping sonars were modeled as stationary sources in a set pattern. Three specific locations on the range were selected based on the range bathymetry. Two of these locations were in the shallower depth regime, and the third was in the deeper regime. Operationally, the source will be deployed at either a deep or a shallow depth. In the model, the source was deployed at a shallow depth at each location. Additionally, the source was modeled at a deeper depth at the deeper location for a total of four analysis points. ALFS was modeled for a period of 5 minutes at each depth and location. (It should be noted that the term "low-frequency" in the ALFS name is somewhat misleading. Although ALFS operates at a frequency lower than the system it will replace (the AN/AQS-13), its operating frequency is in a range more commonly called mid-frequency.)

4.4.3 Surface Ship Sonar (AN/SQS-53C)

The AN/SQS-53C, one of two surface ship sonars that were modeled, would be employed by surface ships in scenarios 2 and 4; it is used on approximately 70% of the surface ships that employ active sonar. The AN/SQS-53C has a higher source level and unique operating characteristics relative to the other surface ship sonar (AN/SQS-56). The surface ship sonar was modeled as a moving source with a fixed depth. Two modes of operation were modeled: search mode and target mode (the latter sometimes referred to as "track mode"). The distribution between search time and target time has been defined as 67% and 33%, respectively. The source characteristics were adjusted in the analysis for each mode of operation.

4.4.4 Surface Ship Sonar (AN/SQS-56)

The AN/SQS-56, the second surface ship sonar that was modeled, would be employed by surface ships in scenarios 2 and 4; it is used on approximately 30% of the surface ships that employ active sonar. As with the AN/SQS-53C, this sonar was modeled in both search mode and target mode, with the source characteristics adjusted accordingly.

4.4.5 Submarine Sonar

The AN/BQQ-5 sonar was modeled as the most representative submarine system. Its employment is included only in scenario 3 (submarine versus submarine). In that scenario, one of the two submarines was assumed to remain silent. The prosecuting submarine was modeled to ping once per hour from one of three stationary positions to confirm targeting solutions. The AN/BQQ-5 was modeled at two operating depths and several locations on the USWTR, with the average result used to calculate exposures for the scenario. Although the submarine moves during an exercise, it was modeled as a stationary source to reflect the fact that its active sonar is rarely used.

4.4.6 Torpedoes

The Mk 46 was modeled as the most representative lightweight torpedo. The Mk 48 EXTORPs are analyzed in scenarios 2, 3, and 4; the Mk 46 EXTORPs are analyzed in scenarios 1, 2, and 4. As with the AN/BQQ-5 submarine sonar, the Mk 48 and Mk 46 EXTORPSs were modeled at two operating depths on the USWTR, but as moving targets rather than stationary.

4.4.7 Fathometers

Fathometers were modeled to operate 100% of the time while involved in scenarios 1 through 4. The fathometer is used by both surface ships and submarines.

4.4.8 Mk 84 Pingers

The Mk 84 is used 100% of the time by the submarine(s) in scenarios 2 through 4.

4.4.9 ADCs

Countermeasures were modeled to function for typical operating times in scenarios 1 through 4. The ADC Mk 3 was chosen for the analysis as the most rcpresentative CM.

4.4.10 Anti-Torpedo Decoy – NIXIE

The NIXIE was modeled as a moving source using typical operating times during scenarios 2 and 4.

4.5 ACOUSTIC MODEL INPUTS

Establishing the acoustic effects on marine mammal populations in the USWTR areas requires identification of the following information regarding acoustic sources: (1) Navy acoustic sources to be used at the training range (see section 4.3), (2) source center frequencies, (3) source output levels, (4) source pulse length and repetition rate, (5) source beamwidth (horizontal and vertical), (6) operating depths at which these sources are to be modeled, and (7) number of training days the acoustic sources are to be used in USWTR waters.

Table 4-4 depicts the combinations of acoustic sources used in the four USWTR training scenarios, as well as estimates of the annual number of training events by scenario. Operational duty cycles are provided for each source. The table also provides surface sonar duty cycles for the two operational modes modeled: search mode and target mode.

Table 4-4. Acoustic Sources Used by Training Scenario and Operational Duty Cycle

Scenario	Participants	Acoustic Sources	Operational Duty Cycles Applied	Estimated USWTR Training Events/Yr
1	P-3 or helicopter versus submarine	ALFS DICASS Mk 84 Pinger Fathometer Mk 46 CM	50% ALFS/50% DICASS	355
2	One helicopter and one surface ship versus submarine	ALFS DICASS SQS-53C SQS-56 Mk 48 Mk 46 Mk 84 Pinger Fathometer CM NIXIE	50% ALFS/50% DICASS 50% helo/50% surface ship 70% SQS-53C (67% search/33% target) 30% SQS-56 (67% search/33% target)	62
3	Submarine versus submarine	BQQ-5 Mk 48 Mk 84 Pinger Fathometer CM	Stationary use (1 ping/hour) Run time	15
4	Two surface ships and two helicopters versus submarine	ALFS DICASS AN/SQS-53C AN/SQS-56 Mk 48 Mk 84 Pinger Fathometer CM NIXIE	50% ALFS/50% DICASS 50% helo/50% surface ship 70% SQS-53C (67% search/33% target) 30% SQS-56 (67% search/33% target)	38

For this analysis, training events and their associated sources were distributed evenly on a seasonal basis. Model inputs are also shown in terms of the acoustic sources used in different scenarios on a yearly basis (see table 4-5).

Table 4-6 lists applicable vessel speeds used in the modeling for each source. Stationary sources include dipping sonar, DICASS sonobuoys, and the AN/BQQ-5 submarine sonar. Submarines move around during an exercise, but their limited use of sonar allows them to be modeled as stationary sources.

Table 4-5. Yearly Acoustic Sources by Scenario

Acoustic Source	Scenario 1	Scenario 2	Scenario 3	Scenario 4
AN/SQS-56	0	18	0	16
AN/SQS-53C	0	42	0	37.33
AN/BQQ-5	0	0	20	0
Mk 48	0	15	30	10
Mk 46	0.89	1.6	0	2.8
ALFS	360	60	0	53.33
DICASS (Two units/deployment)	360	60	0	53.33
Mk 84 Pinger	360	30	40	40
Fathometer-Surface Ship	0	60	0	80
Fathometer-Submarine	360	60	40	40
CM (ADC Mk 3)	10	4	8	12
NIXIE	0	15	0	10

Table 4-6. Modeled Source Platform Speeds

Source Type	Modeled Speed (km/hr)
AN/SQS-56	18.5
AN/SQS-53C	18.5
AN/BQQ-5	NA (Stationary Source)
Mk 48	Classified
Mk 46	Classified
ALFS	Stationary (three locations)
DICASS	Stationary (three locations)
Mk 84 Pinger	Platform-dependent
Fathometer	Platform-dependent
ADCs	Classified
NIXIE	Classified

5. UNDERWATER SOUND PROPAGATION ANALYSIS

The initial modeling step consists of calculating the acoustic propagation loss. Studies show that spherical spreading loss provides a good approximation for Level A harassment analysis. Conversely, Level B harassment analysis requires modeling for a combination of variables. The variables include season, defined depth regions, and the source's operational characteristics (frequency, vertical and horizontal beam pattern, ping length, depth). Each analysis run incorporates bottom and surface reflection losses, multipath reception of sound, absorption, and ray traces resulting from the seasonal sound speed profile (SSP).

5.1 LEVEL A HARASSMENT PROPAGATION MODELING

When the threshold level for Level A harassment was compared to source characteristics for the systems analyzed, it was apparent that a detailed propagation analysis would overcomplicate the analysis without offering a significant benefit—a finding based on the short distances necessary to reach the Level A thresholds with spherical spreading losses alone. An example is shown in table 5-1 for a source assumed to ping with a pulse length of 1 second. As a result of these short distances, few or no surface and bottom interactions occur, and absorption is negligible in comparison to spreading losses. Also, there is little accumulation of energy from multiple pings above or near the thresholds for moving sources; the Level A harassment range, therefore, corresponds closely to the range for each ping independently. Thus, to determine the Level A harassment range for each source, propagation losses were modeled as being equal to spherical spreading losses. For sources where multiple pings from a single point would occur, such as dipping sonar, the harassment range was determined by the SEL from all pings at each transmission point.

Table 5-1. Level A Harassment Range Example

Source Level (dB//1 µPa @ 1 m)	Ping Length (s)	SEL (dB//1 µPa^2 · s)	Level A Threshold (dB//1 µPa^2 ·s)	Allowable Spreading Loss (dB re 1 µPa)	Distance to Reach Level A Threshold (20 log R)(m)
215	1	215	215	0	1.0
220	1	220	215	5	1.8
225	1	225	215	10	3.1
230	1	230	215	15	5.6

Some caveats exist for the Level A harassment analysis, all of which produce an expectation of few or no Level A harassment exposures. First, for physically larger sources (surface ship sonar and submarine sonar), Level A harassment ranges can be close to the acoustic transducers. In this circumstance, the actual level of harassment experienced by a marine mammal will be limited by the sonar structure's shielding effects. Second, the analysis assumes that the acoustic energy is constant throughout the vertical water column at a given horizontal range from the source. For short distances, the slant range between the source and mammal may significantly exceed the horizontal distance, resulting in a lower energy level being received.

Third, for lower power sources, the harassment range may be less than the size of the mammal itself. Fourth, the Level A harassment ranges for all sonars correspond to distances where striking the animal is possible. Mitigation measures to avoid ship strikes of marine mammals simultaneously eliminate the potential for Level A harassment. The likelihood of Level A harassment is very low; its assessment was included for completeness.

5.2 LEVEL B HARASSMENT PROPAGATION MODELING

For Level B harassment, propagation analysis is performed using the Gaussian Ray Acoustic Bundle (GRAB) model for horizontally stratified and range-variant environments. GRAB provides detailed multipath information as a function of range and bearing. The Gaussian beam approach provides a means for estimating energy leakage out of ducts and into shadow zones, significantly improving ray-based model predictions and extending the operational realm to lower frequencies. GRAB allows input of range-dependent environmental information so that, for example, as bottom depth and sediment type change across a range, their acoustic effects can be modeled. The propagation analysis uses the input data described in section 5.3, in addition to the source's frequency, pulse length, and vertical beam pattern.

Range-dependent models, such as those based on a parabolic equation (PE) (for example, University of Miami PE, Finite Element PE, and Navy Standard PE), are accurate and were considered. Using these models, however, requires increasingly longer computer run times as the source frequency increases. While there is no inherent frequency limitation to PE models, the higher the acoustic frequency and fidelity of the environmental inputs modeled, the more memory and computer processing time that is required. The GRAB eigenray propagation loss program has received full Oceanographic and Atmospheric Master Library (OAML) approval for modeling acoustic systems that operate in the range of 150 Hz to 100 kHz. For each path to a given receive point, the total energy from all eigenrays is used to produce a propagation loss function. See figure 5-1.

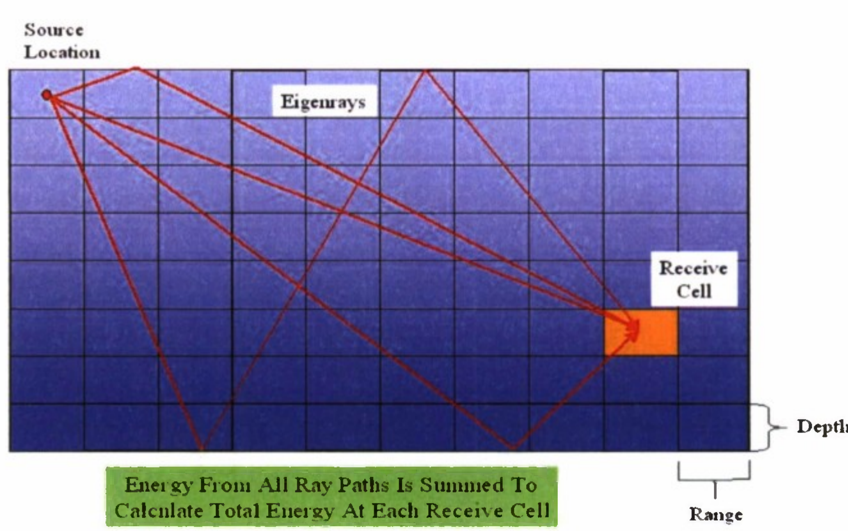

Figure 5-1. Comprehensive Acoustic System Simulation (CASS)/GRAB Propagation Loss Calculations

5.3 ACOUSTIC ENVIRONMENT

Several environmental inputs are necessary to model acoustic propagation on the prospective ranges: bathymetry, seasonal wind speeds, seasonal SSPs, and bottom characteristics. Wind speeds are averaged for each season to correspond with the seasonal SSPs.

5.3.1 Bathymetry

Bathymetry data for the Jacksonville site were obtained from the Naval Oceanographic Office (NOO) Digital Bathymetric Data Base-Variable (DBDB-V) (NOO CD, 2007). A map of this area is shown in figure 5-2. The training range is represented by a 35- by 48-km parallelogram. The resulting bathymetry map covers an area larger than the proposed range to account for acoustic energy propagating off the training area.

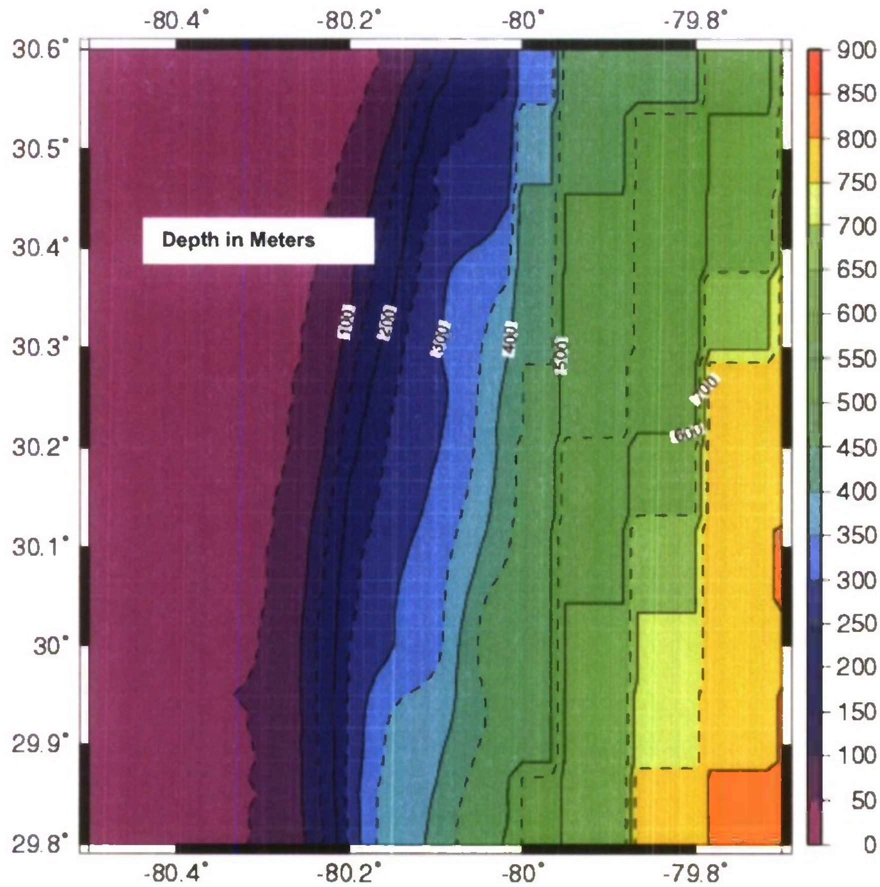

Figure 5-2. Jacksonville Bathymetry (Range Center at 30.27° N, 80.22° W) (NOO, 2007)

Bathymetry data for the Charleston site (figure 5-3) were also obtained from the NOO DBDB-V (NOO, 2007). The training range area is represented by a 36- by 45-km quadrangle. The resulting bathymetry map covers an area larger than the proposed range to account for acoustic energy propagating off the training area.

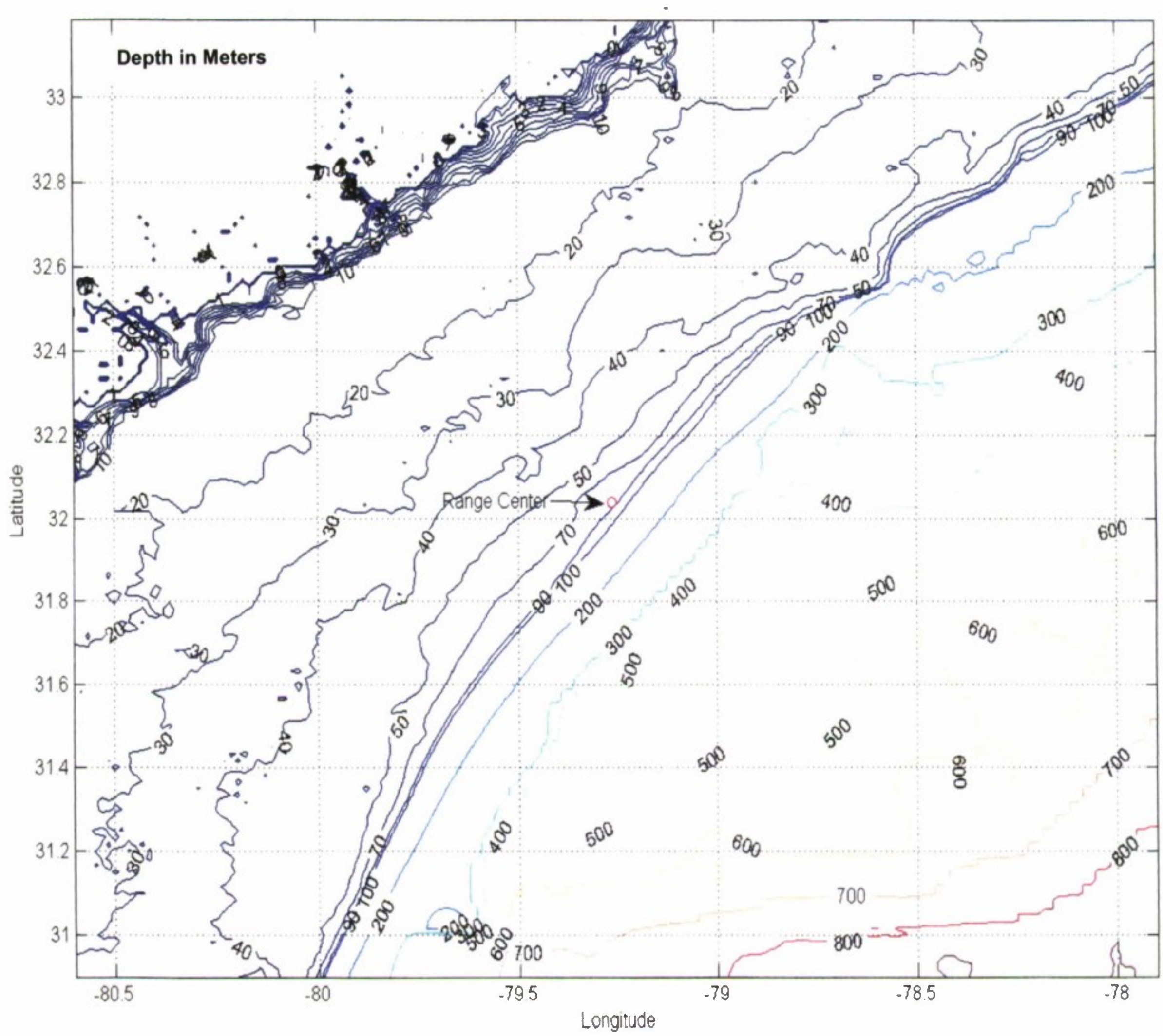

Figure 5-3. Charleston Bathymetry (Range Center 32.04° N, 79.27° W) (NOO, 2007)

Bathymetry data for the Onslow Bay site (see figure 5-4) were obtained from the National Oceanographic and Atmospheric Administration (NOAA) National Geophysical Data Center, Coastal Relief #1 and #2 East Coast CD-ROM databases. The bathymetry contours were extended from the surveyed area into deeper waters to cover the extent of acoustic propagation. This extrapolation permits uniform acoustic analysis of the area. The training range area is represented by a 40- by 50-km rectangle. The bathymetry map (150 by 110 km) covers a region larger than the range area.

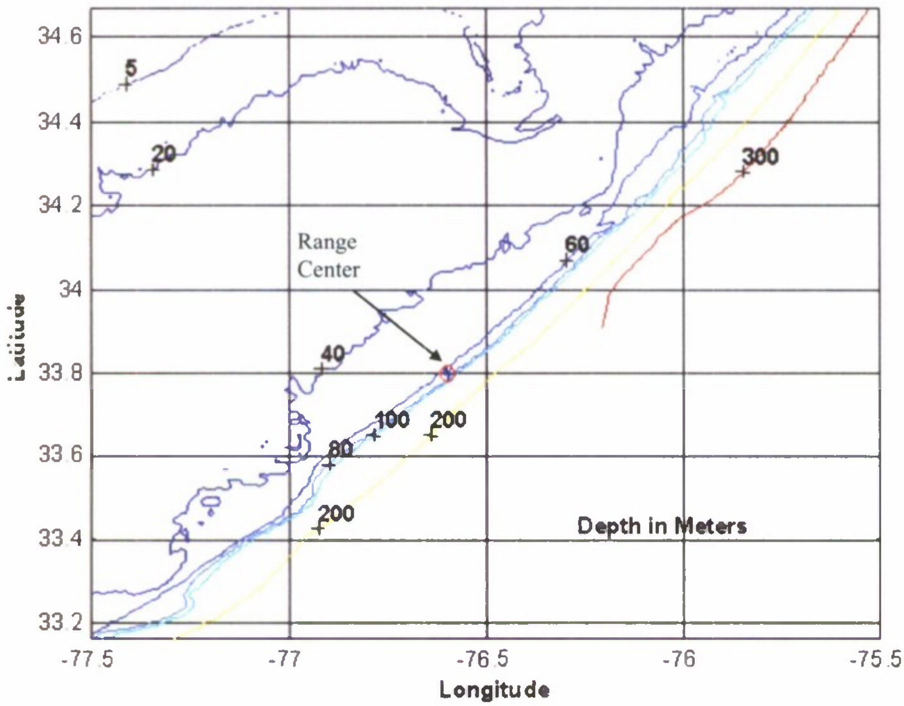

Figure 5-4. Onslow Bathymetry (Range Center at 33.8° N, 76.6° W) (Taken from NOAA National Geophysical Data Center, Coastal Relief #1 and #2 East Coast CD-ROM Databases)

Bathymetry data for the Wallops Island site (figure 5-5) were obtained from the National Geophysical Data Center, Coastal Relief Model (volume II). To use these data in the acoustic propagation model, these data were translated and rotated onto xy-coordinates to be consistent with GRAB input parameters. The bathymetry contours did not have to be extended from the surveyed area because the database covered the entire area. The other edges of the region were treated as projections of the edge for the analysis. The training range area is represented by a 40- by 50- km rectangle. The resulting bathymetry map (130 by 100 km) covers an area larger than the range area; the acoustic energy propagating off the training area, therefore, can be accounted for.

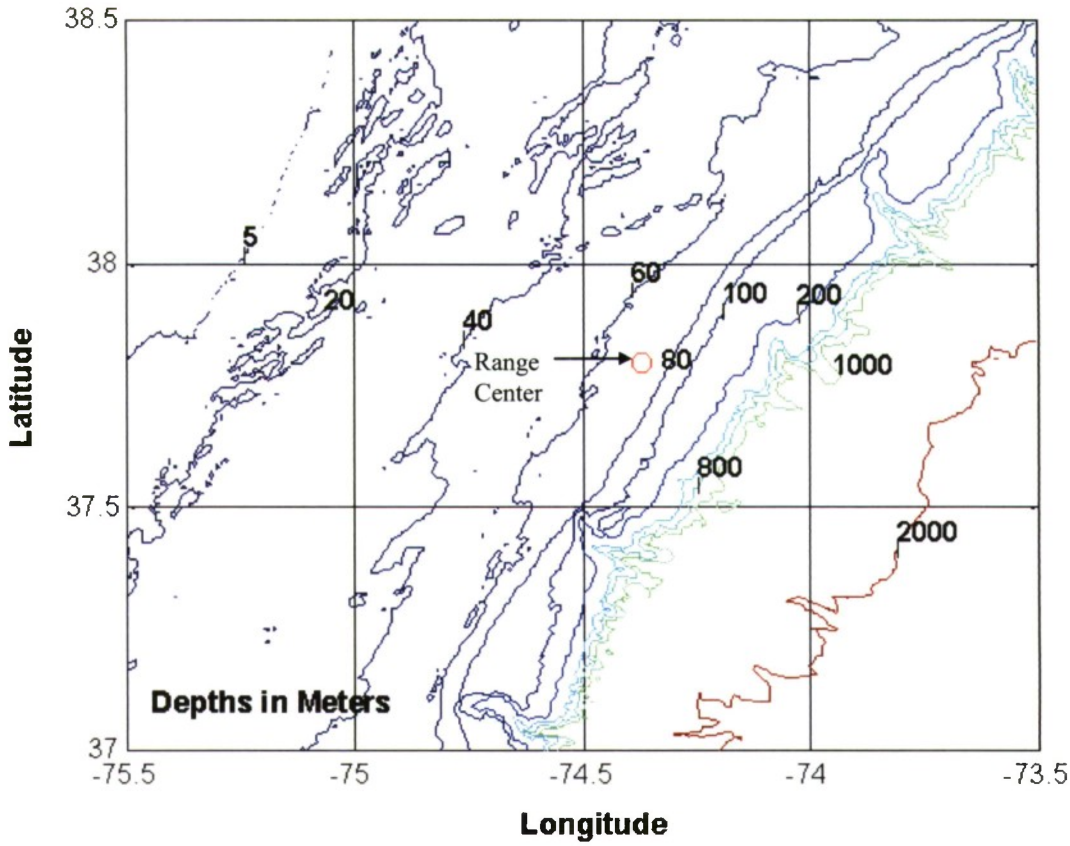

Figure 5-5. Wallops Island Bathymetry (Range Center at 37.8° N, 74.36° W) (Taken from the NOAA National Geophysical Data Center, Coastal Relief Model (Volume II)

5.3.2 Wind Speed Data

Wind speed data for Jacksonville (see table 5-2) were collected from Mine Warfare Pilot, Kings Bay. The wind speeds were averaged for each season and range from 7.3 to 9.8 m/s. These averages are based on more than 96 observations.

The National Data Buoy Center (NDBC) website (http://www.ndbc.noaa.gov), maintained by the NOAA, provided wind speed data for the Charleston, Onslow Bay, and Wallops Island sites. The Charleston data reflect wind speed measurements from buoy number 41004 from June 1978 through December 2001 (see table 5-3). Wind speed data for Onslow Bay include wind speed measurements from June 1976 through December 1993 (see table 5-4). Buoy number 41001 is the offshore measurement station nearest Onslow Bay; it is located 150 nmi east of Cape Hatteras at coordinates 34.68° N, 72.23° W. Wind speed data for Wallops Island is provided in table 5-5.

Table 5-2. Seasonal Wind Speed Average for Jacksonville

Season	Wind Speed (knots)
Winter	9.8
Spring	7.7
Summer	7.3
Autumn	9.4

Table 5-3. Seasonal Wind Speed Average for Charleston

Season	Wind Speed (knots)
Winter	7.3
Spring	6.3
Summer	5.8
Autumn	6.5

Table 5-4. Seasonal Wind Speed Average for Onslow Bay

Season	Wind Speed (knots)
Winter	9.4
Spring	8.0
Summer	6.1
Autumn	7.3

Table 5-5. Seasonal Wind Speed Average for Wallops Island

Season	Wind Speed (knots)
Winter	11.1
Spring	11.5
Summer	9.0
Autumn	10.0

5.3.3 Surface Loss Model

The surface loss model used in CASS was assessed using at-sea measured propagation loss data, which were acquired as part of a comprehensive side-by-side test of MF and LF sonars in February 1992 (Lanza, 1992). Based on an analysis of these data, the most applicable surface reflection model for a marine mammal acoustic effects assessment within the CASS environment is the modified-Eckart model (Ward, 2001).

5.3.4 SSPs

An investigation was conducted to determine seasonal acoustic characteristics of the four sites. SSPs for Jacksonville and Charleston were obtained from the NAVOCEANO Generalized Digital Environmental Model (NAVOCEANO GDEM-V). Comparison of these SSPs to those of the other two sites reveals that the Jacksonville and Charleston range area SSPs are similar to that of the Onslow Bay area. These three sites are subject to daily variations attributed to their proximity of the Gulf Stream.

SSPs from 1980 to 2005 for Onslow Bay and Wallops Island were downloaded from the National Oceanographic Data Center (NODC) Oceanographic Profile Database (www.nodc.noaa.gov/). For Onslow Bay, 346 SSPs were obtained, 35 of which were determined to have inconsistent data and were discarded. Of the remaining profiles, 55 were on the Continental Shelf (less than 60 m depth), 83 were at the shelf break (between 60- and 200-m depth), and 173 were on the continental slope (greater than 200-m depth). The three sets were then grouped by season. A summary of the Onslow Bay SSPs is provided in table 5-6. For Wallops Island, 1193 profiles were available and are summarized in table 5-7.

Table 5-6. Onslow Bay SSP Distribution

Depth Regime	**Spring**	**Summer**	**Autumn**	**Winter**
Continental Shelf	9	13	3	30
Shelf Break	14	18	9	42
Continental Slope	58	26	20	69

Table 5-7. Wallops Island SSP Distribution

Depth Regime	**Spring**	**Summer**	**Autumn**	**Winter**
Continental Shelf	119	278	23	259
Shelf Break	78	101	18	143
Continental Slope	24	92	48	10

Within each depth regime and season combination, the most representative SSP was selected by determining which profile most closely matched the average of the profiles. To determine the average, each profile was stratified into 1-meter depth increments. Interpolation was used to produce a uniform number of data points in each profile. The average profile was calculated by averaging each of the depth layers for all of the profiles in the set. The profile used in the analysis was the profile whose sum of the squares of the differences from the average profile was the least.

The best Continental Slope profiles selected were not deep enough to define the sound speed environment over the deeper parts of the range space for the CASS/GRAB model; therefore, to define SSPs for deeper parts of the slope, the appropriate lower section of the deepest profile was added onto the selected profile. SSPs used for the Jacksonville, Charleston, Onslow Bay, and Wallops Island sites are shown in figures 5-6 through 5-9, respectively.

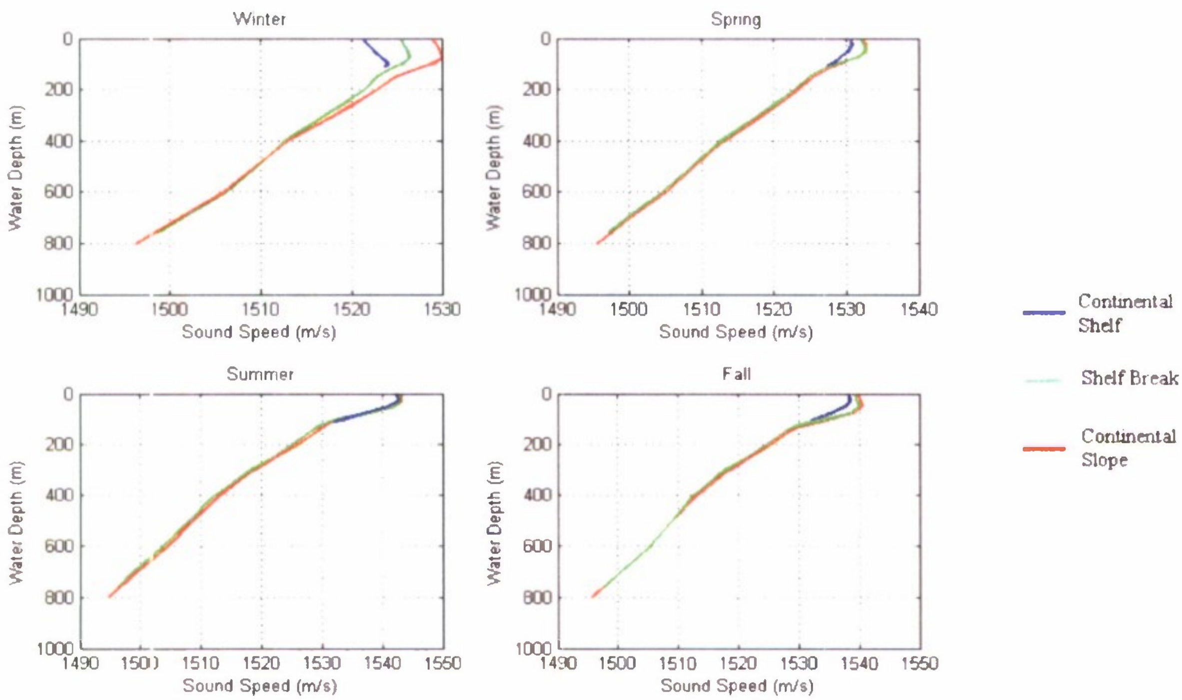

Figure 5-6. SSPs for Jacksonville Analysis

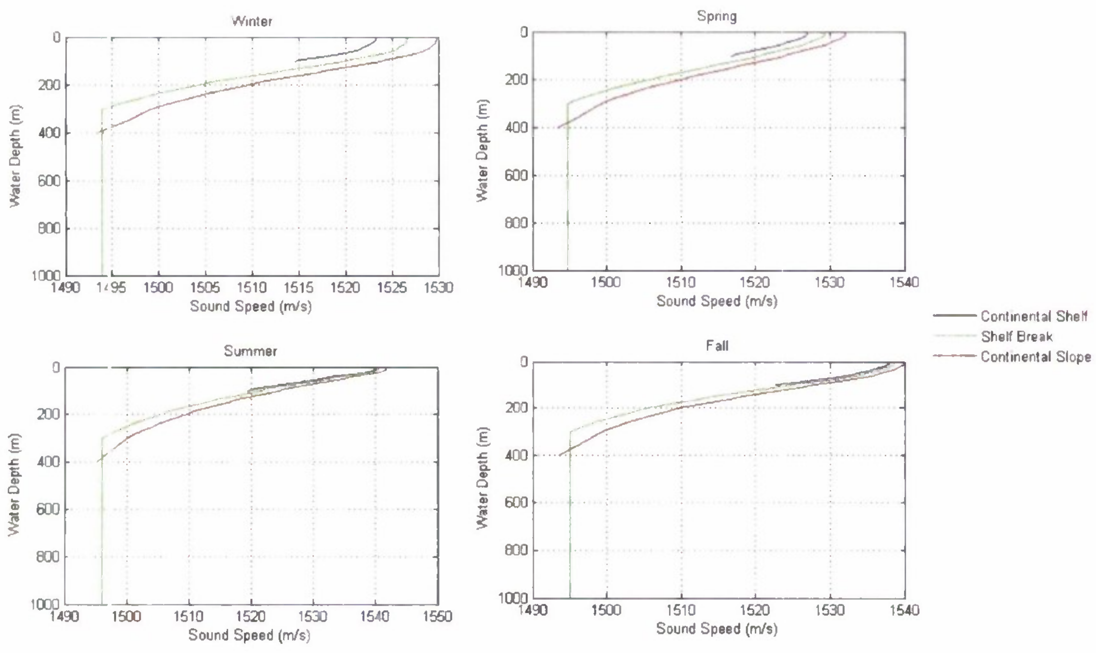

Figure 5-7. SSPs for Charleston Analysis

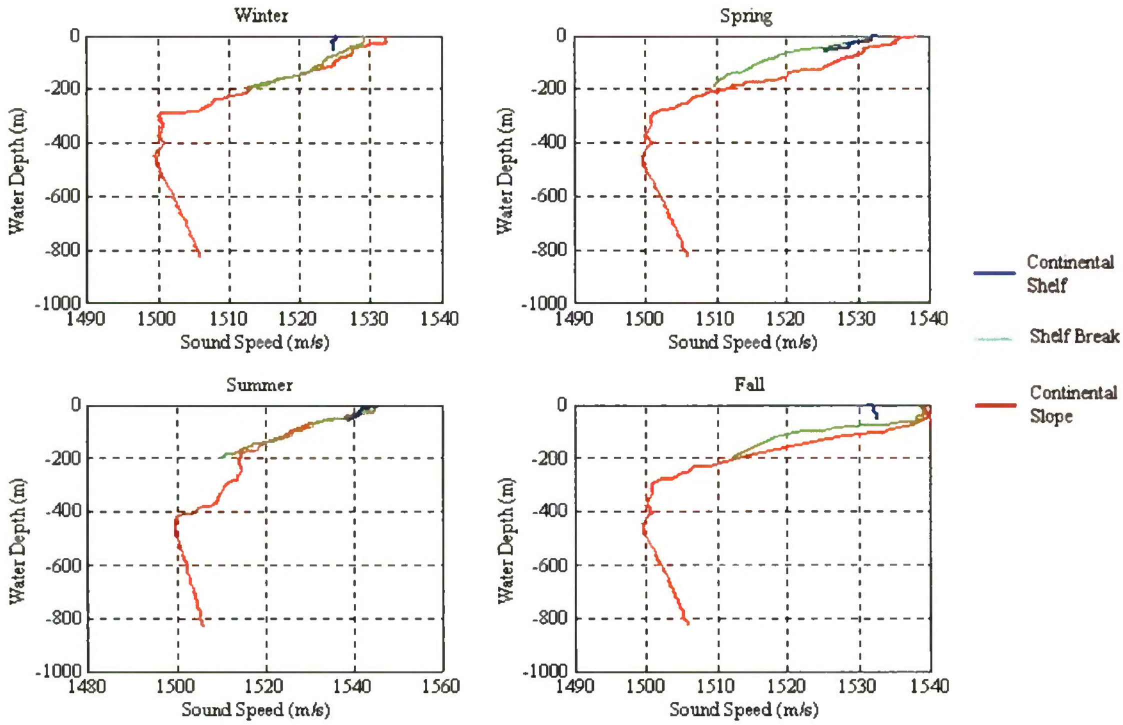

Figure 5-8. SSPs for Onslow Bay Analysis

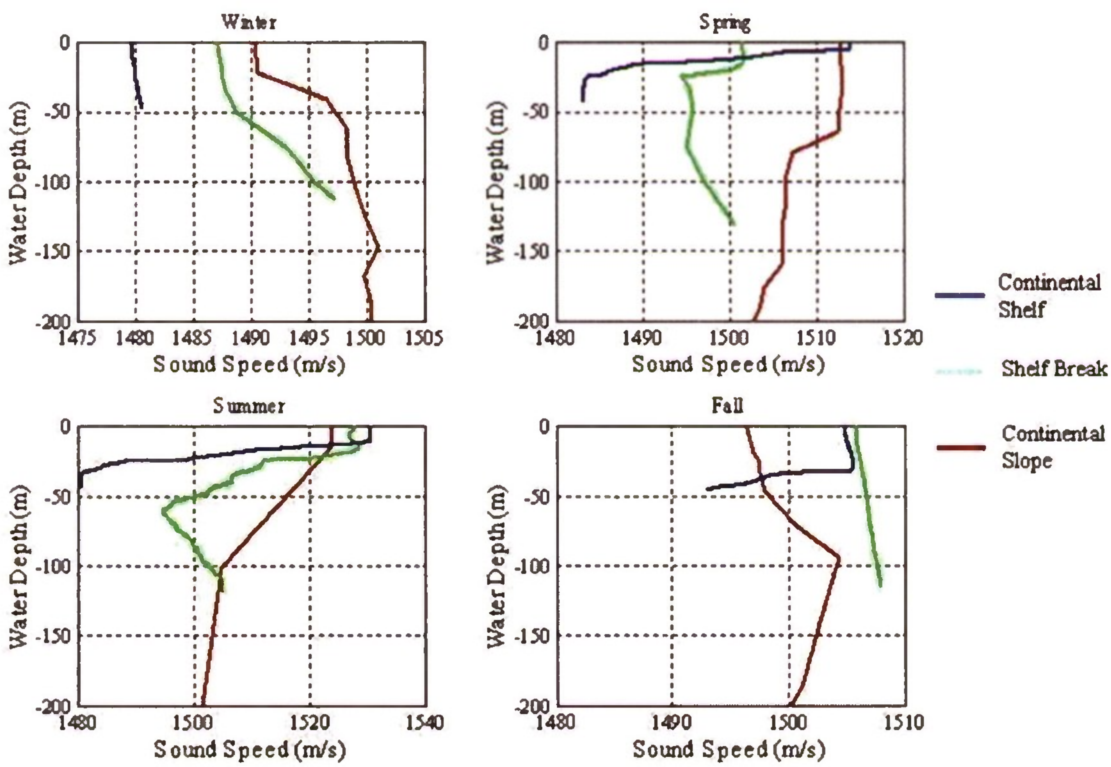

Figure 5-9. SSPs for Wallops Island Analysis

5.3.5 Sediment Characteristics and Bottom-Loss Model

Bottom type information for the Jacksonville and Charleston sites were obtained from a DoN marine resource assessment (DoN, 2007b).

The Navy's standard bottom loss reflection coefficient model for frequencies < 10 kHz is the Low-Frequency Bottom-Loss (LFBLTAB) model. This model requires a detailed description of the physical characteristics of the bottom sediment, such as bottom sound speed, bottom depth, two-way travel time to the geological basement, water-to-bottom sound-speed ratio, thin-layer thickness, and thin-layer sediment density. A more detailed list of the required inputs is documented by Weinberg et al. (2001). The Naval Research Laboratory published several technical documents describing the geoacoustic properties of Long Bay, an area immediately south of Onslow Bay (Gomes, Fisher, Celuzza, and Abbott, 2000 and Gomes, Fisher, Fulford, et al., 2000; Erskine, 1998). Sediment characteristics for the three regimes within the Long Bay area were extrapolated to Onslow Bay using available side-scan and sub-bottom data to classify the area within each regime. The output of the LFBLTAB model is a table of the bottom–loss reflection coefficient as a function of grazing angle.

Data on bottom type for the Wallops Island site were obtained from a Woods Hole Oceanographic Institution report (Hathaway, 1977). These data provided an adequate picture of bottom types, but they provided too few input parameters to use in the CASS GeoAcoustic Module. Results at the Wallops Island site delineated the site into a sandy bottom Continental Shelf regime and a muddy sediment bottom Continental Slope regime.

The Applied Physics Laboratory, University of Washington (APL/UW) bottom-loss model was also used because one acoustic source operates at a frequency greater than 10 kHz. Marine Geophysical Survey (MGS) bottom-loss data are required for this model. The respective bottom types were chosen to correspond to the sediment type found in each proposed OPAREA.

In the GRAB propagation model, the bottom can be characterized in several ways. Because of the large spread in acoustic frequencies, two standard models were used: (1) the MGS bottom-loss data for mid-frequencies (2 – 5 kHz), and (2) the Rayleigh model (which docs not need MGS application) for frequencies > 5 kHz. The Rayleigh model is the CASS implementation of the APL/UW bottom-loss model for high frequencies. Bottom types for each model were chosen to correspond to the sediment types found in the training areas and are listed in tables 5-8 (Jacksonville and Charleston) and 5-9 (Onslow Bay and Wallops Island).

Table 5-8. Bottom Types for Jacksonville and Charleston

Jacksonville			Charleston		
Depth Region (m)	Sediment Type*	APL/UW† TR 9407 HF Grain Index	Depth Region (m)	Sediment Type*	APL/UW† TR 9407 HF Grain Index
20 – 60	Coarse Sand	0.5	20 – 60	Muddy Sand	3.0
60 – 200	Sand/Silt/Clay	5.5	60 – 200	Muddy Sand	3.0
200 – 800	Sand/Silt/Clay	5.5	200 – 800	Muddy Sand	3.0
Sources: *Hathaway (1977); † APL/UW (1994).					

Table 5-9. Bottom Types for Onslow Bay and Wallops Island

Onslow Bay			Wallops Island		
Depth Region (m)	Sediment Type*	APL/UW† TR 9407 HF Grain Index	Depth Region (m)	Sediment Type*	APL/UW† TR 9407 HF Grain Index
20 – 60	Hard Sand	1.5	20 – 60	Coarse Sand	1.5
60 – 200	Transition Hard Sand to Mud	4.0	60 – 200	Transition Coarse Sand to Fine Sand	3.5
200 – 2000	Sediment (Mud)	4.0	200 – 1000	Transition Fine Sand to Green Mud	5
			1000 – 2000	Green Mud	5
Sources: *Hathaway (1977); † APL/UW (1994).					

5.4 PROPAGATION MODEL CONSIDERATIONS

The SEL for all pings will exceed the level of the loudest ping when multiple pings are received at any point. To calculate the accumulation of energy from multiple pings, an acoustic propagation analysis must be performed up to a distance ensuring that the potential for cumulative energy exceeding the harassment thresholds is assessed. The extent to which RLs must be accumulated below the threshold depends on the source's operational characteristics, including SL, source movement, ping duration, and ping repetition rate. Level B behavioral harassment is calculated with a predefined risk function that requires the propagation analysis to be performed up to the range at which the maximum SPL received is 120 dB re 1 μPa. Based on this criterion, propagation losses were calculated to a range of 100 km around each point of both moving and stationary sources. The CASS model requires specification of the water depth and distance intervals, 2m and 5 m, respectively.

Each of the proposed USWTR sites has range-varying bathymetry and sediment types in addition to seasonal SSP changes—all of which present a challenge to model effectively and within realistic time constraints. One common feature of all sites is the parallel nature of the bathymetric contours, which allows the number of propagation bearing angles from each source to be reduced because of left/right symmetry. The bearing angles modeled were 0°, 45°, 90°, 135°, and 180°. The results for 45°, 90°, and 135° are reused for 315°, 270°, and 225°, respectively. The bearing angle symmetry is shown in figure 5-10.

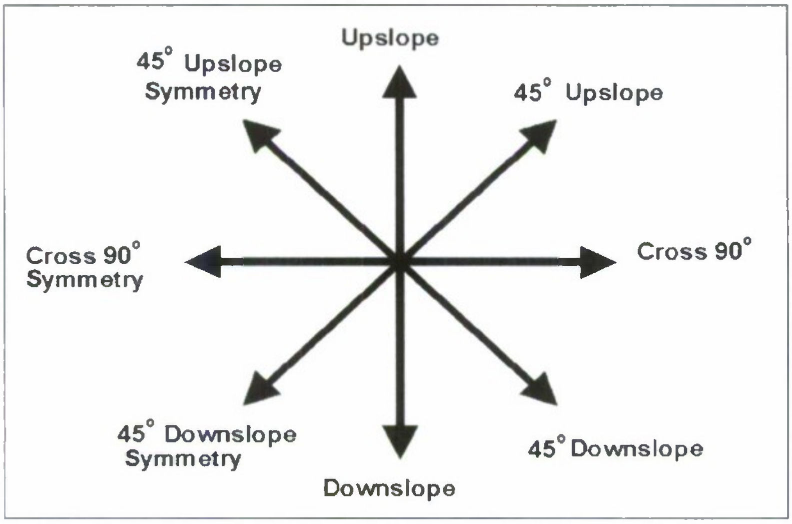

Figure 5-10. Bearing Angle Symmetry for Propagation Analysis

Examination of the variability of propagation loss at the proposed Jacksonville, Charleston, Onslow Bay, and Wallops Island USWTR sites was conducted. Propagation losses vary with surface and bottom interaction, which in turn are a function of water depth. An illustration of this effect is shown in an extended distance propagation analysis (figure 5-11), where distinct points of surface and bottom reflections are visible. These are also points where energy from multiple ray paths is present. As a result of this examination, the number of water depths modeled was reduced to three. This small number of depth regimes adequately represents propagation variability while limiting the complexity of the modeling effort. Source positions for propagation modeling were limited to three depth regimes: (1) 20 to 60 m – Continental Shelf, (2) 60 to 200 m – shelf break, and (3) 200 to 2000 m – Continental Slope.

The range maps (figures 5-12 through 5-15) show the source positions selected for propagation modeling. These positions were translated into xy-coordinates to be consistent with GRAB input parameters.

Even with the reduced number of angles and source positions modeled, hundreds of propagation runs were conducted to represent multiple source types, source depths, source frequencies, seasonal changes, depth regimes, and operating modes.

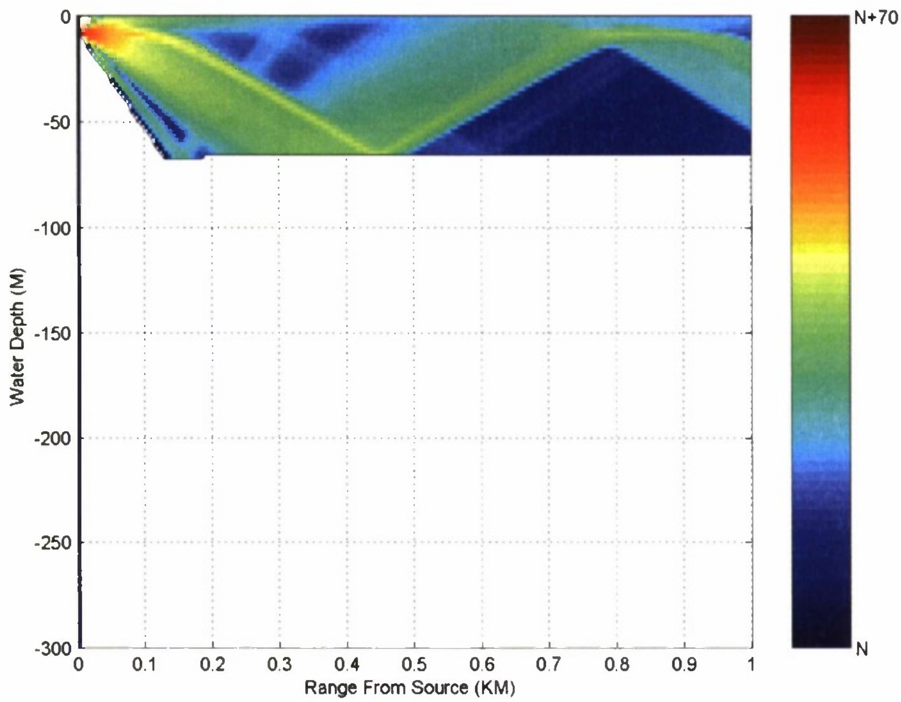

Figure 5-11. Sample Propagation Analysis Illustrating Boundary Interactions

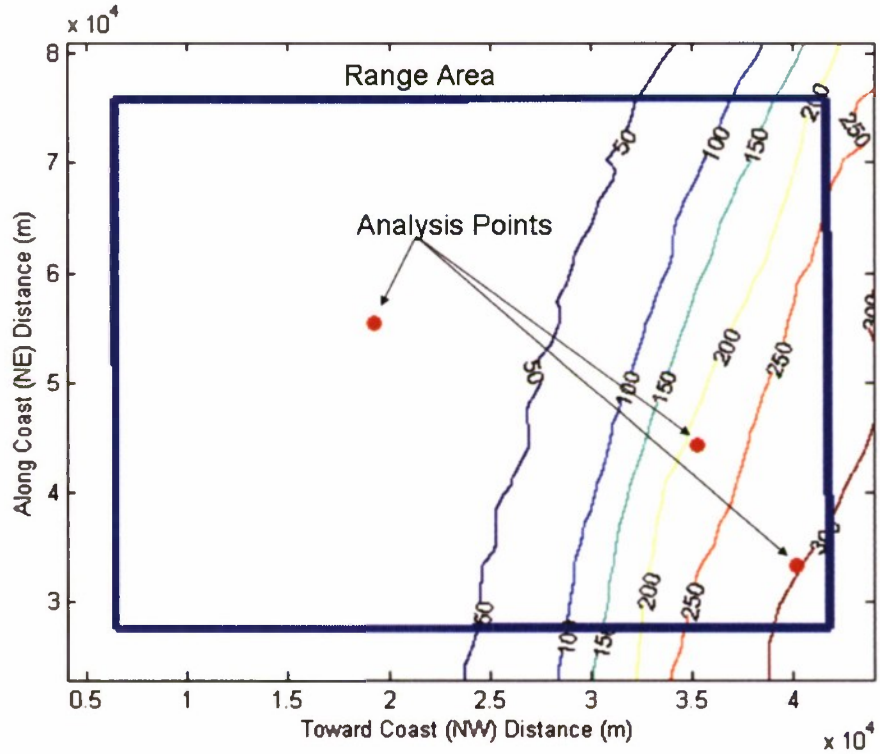

Figure 5-12. Jacksonville Selected Source Positions for Propagation Modeling

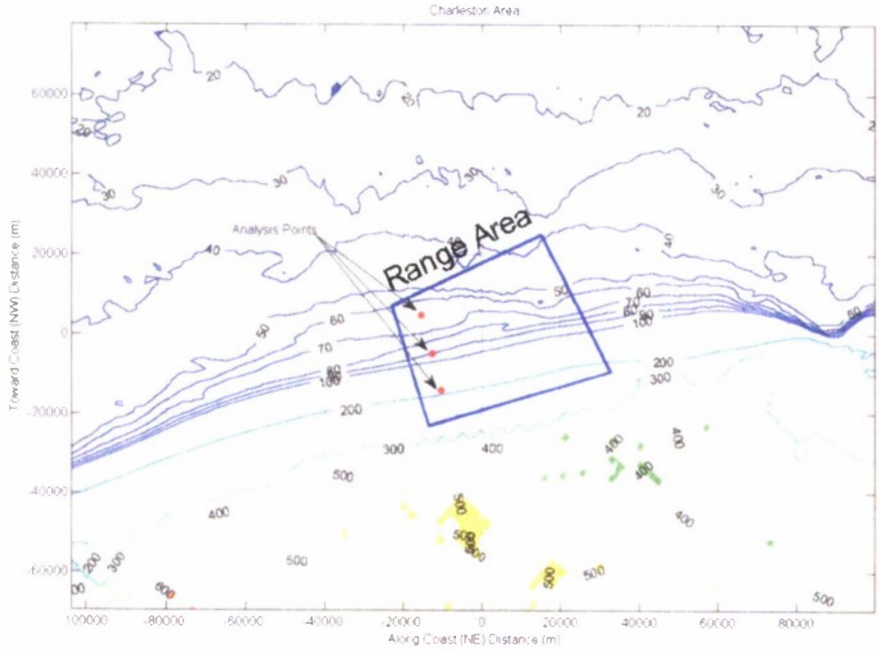

Figure 5-13. Charleston Selected Source Positions for Propagation Modeling

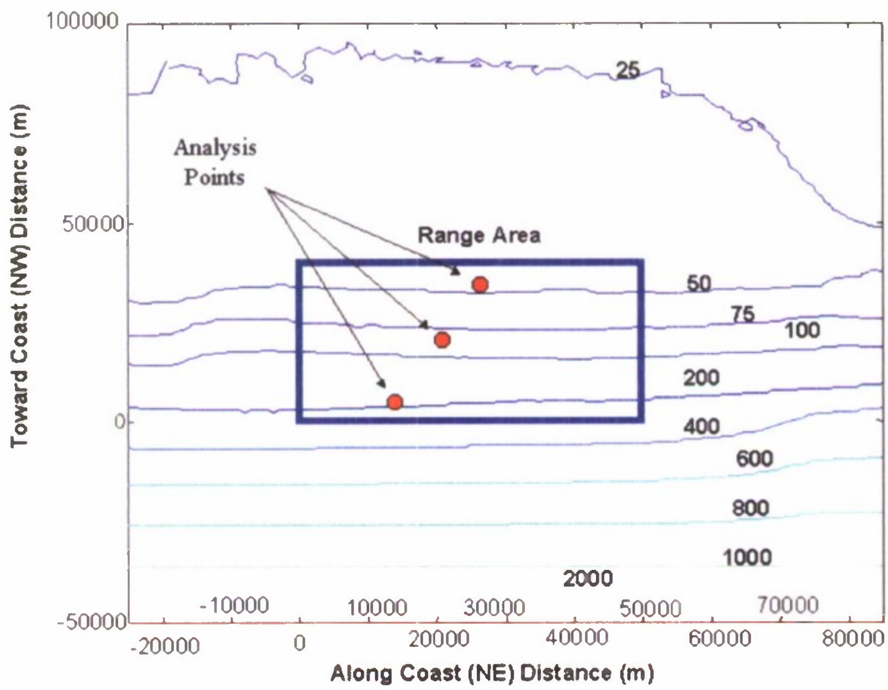

Figure 5-14. Onslow Bay Selected Source Positions for Propagation Modeling

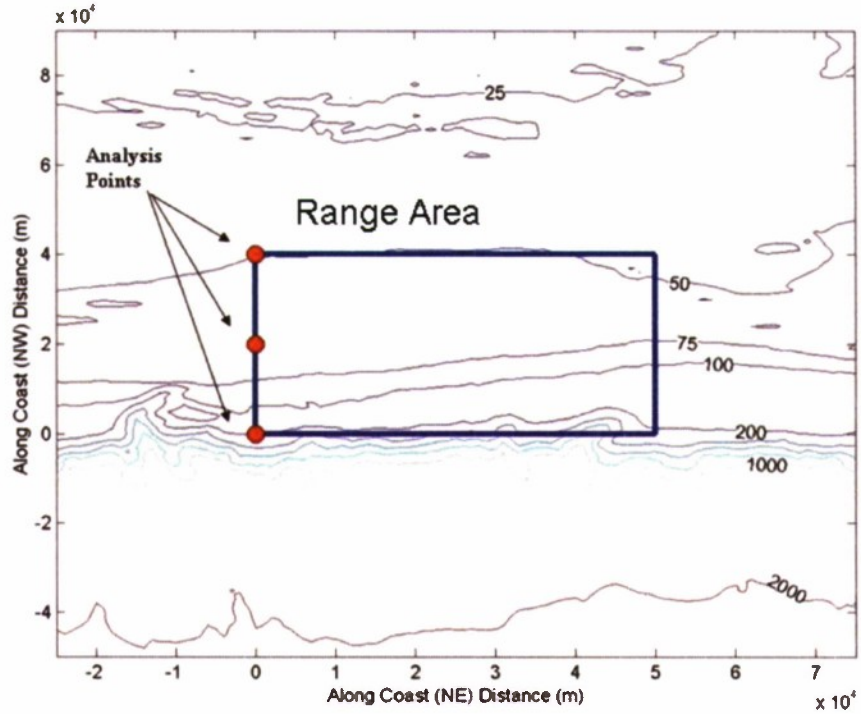

Figure 5-15. Wallops Island Selected Source Positions for Propagation Modeling

6. EXPOSURES CALCULATION

This section describes the method by which the estimated number of exposures is calculated for marine mammals that would be subjected to acoustic source levels above the applicable acoustic effects thresholds. This analysis combines the data on marine mammal distribution and density from section 2, the Level A and Level B harassment thresholds summarized in section 3, the Navy source and scenario definitions in section 4, and the acoustic propagation analysis described in section 5.

6.1 ASSUMPTIONS

Marine mammal distribution, hearing, and diving behavior are considered essential elements to the exposure prediction model. In this analysis, no attempt was made to predict animal behavior in response to sound in the water or animal location relative to the point where the acoustic source initiates operation; it was assumed that marine mammals have omnidirectional hearing. This approach was used because no information was provided for the marine mammal responses over time to the acoustic sources. Diving behavior of the marine mammals was not modeled. It was assumed that marine mammals were exposed to the maximum RLs calculated for the horizontal distance to the source, regardless of their water depth. For each depth regime, animals were distributed with a static, uniform density across the range area.

6.2 ACOUSTIC FOOTPRINT CALCULATION

An acoustic footprint was created for each CASS propagation analysis run. This set of footprints delineates propagation variation versus source operating mode, season, and operating depth for each analysis point.

The first step in calculating an acoustic footprint is to convert CASS propagation loss versus range and depth for each bearing angle to a single, maximum RL versus range curve, as shown in figure 6-1. This step is accomplished by filtering the minimum propagation loss at each range increment and adding the source's output SPL. Note that the actual curves are classified because of the inclusion of SL data.

The acoustic footprint for omnidirectional sources was generated by translating the maximum RL versus range along the eight bearing spokes into a continuous, two-dimensional array. The maximum RL curve for each bearing angle was used to populate all angles around the source by "spreading" the curve ±22.5° on either side of the specific bearing spoke, which results in a continuous, 360° characterization of the RL from the source, as shown in figure 6-2. The resulting sectors are each 45° wide. A single RL is used at a fixed range from the source within the sector. Slope references (that is, upslope, downslope, cross-slope) refer to the direction of sound propagation that was modeled, not source movement.

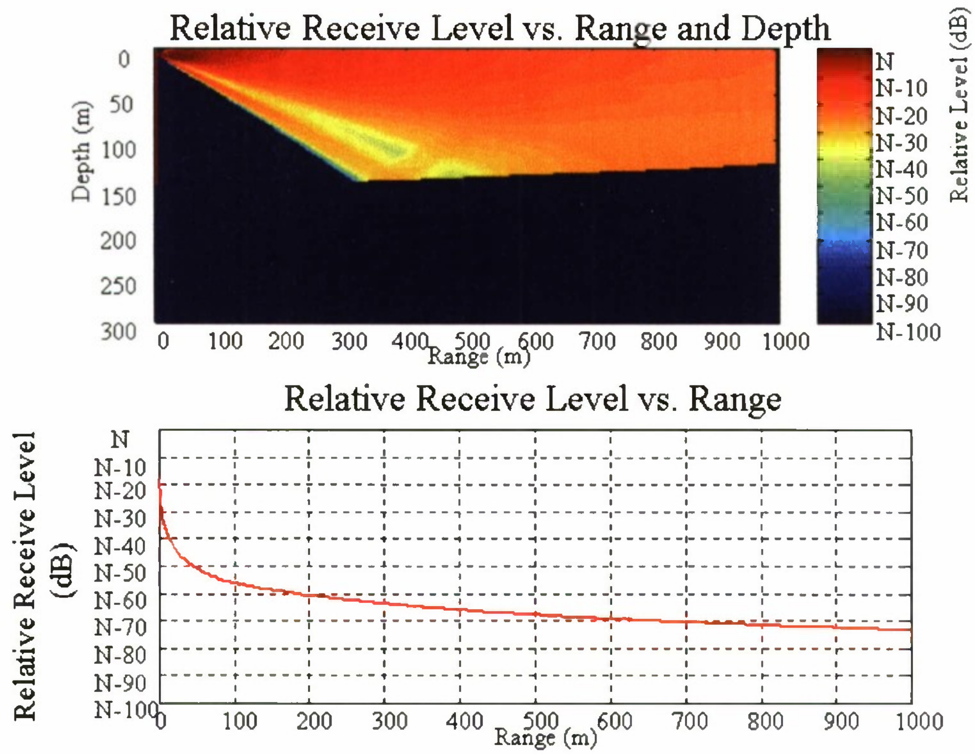

Figure 6-1. CASS Propagation Output and Corresponding Maximum RL Versus Range Curve

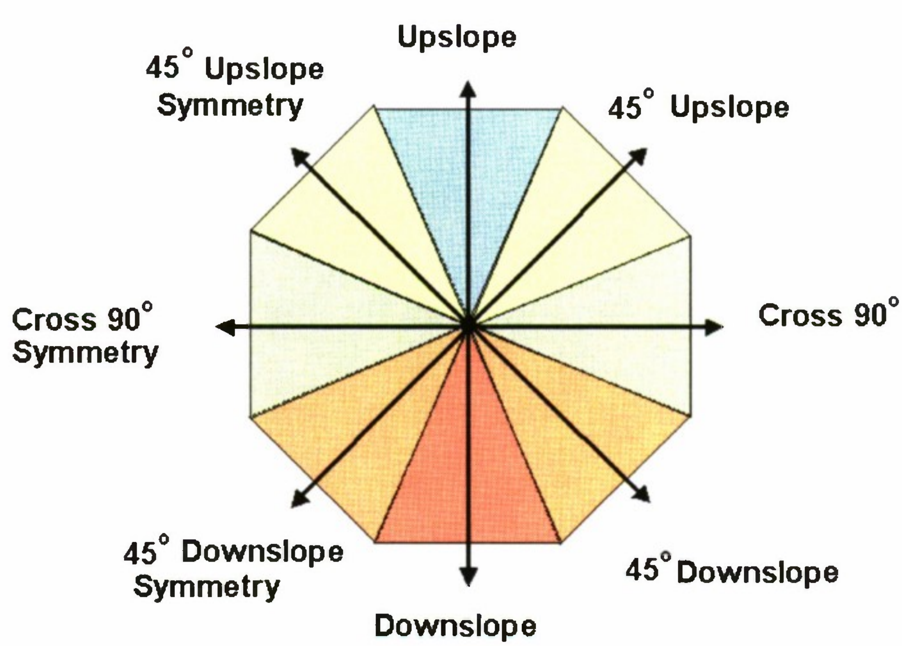

Figure 6-2. Acoustic Footprint Calculation from CASS Propagation Curves Along Modeled Bearing Angles

Two example acoustic footprints are shown in figure 6-3. The RL is color-coded, with red indicating the strongest signals and blue indicating the weakest signals. The Continental Slope example highlights greater variability in RL versus propagation direction.

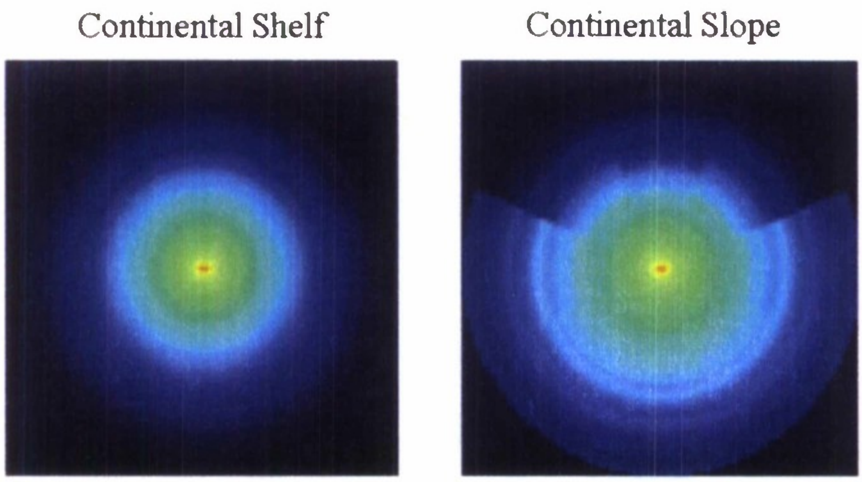

Figure 6-3. Examples of Acoustic Footprints for Continental Shelf (Left) and Continental Slope (Right) Depth Regimes

The acoustic footprint for stationary directional sources was generated for sectors that lie within the source's horizontal beamwidth. The beamwidth for moving directional sources was centered along the main response axis oriented in the direction of movement, that is, cross-slope, upslope, or downslope (see figure 6-4 for an example of a cross-slope footprint example).

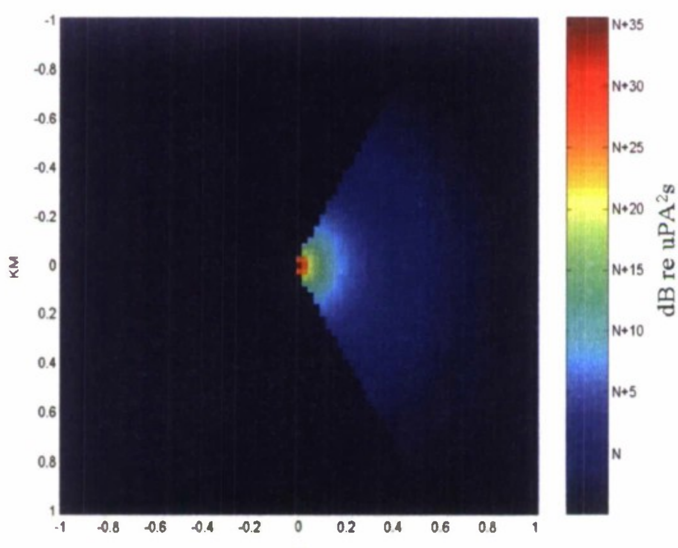

Figure 6-4. Applying a Beam Pattern for a Directional Acoustic Footprint

For directional stationary sources, variation in footprint orientation was captured by calculating the three footprints facing upslope, downslope, and cross-slope. In all cases, the acoustic footprint size is matched to the CASS propagation distance of 100 km, resulting in a footprint of 100 km in radius.

The distance resolution in the acoustic footprint (25 m) is five times that of the CASS propagation analysis. Thus, each data point within the acoustic footprint represents an area of 0.000625 km^2. The maximum RL of the five points within the 25-m interval is selected as the single data point for the acoustic footprint. For example, the minimum loss at 105, 110, 115, 120, and 125 m would be used for the single footprint value covering 100 to 125 m. An analysis was conducted to determine the maximum decimation factor that could be used without compromising the accuracy of the exposure estimates. The benefit of this process is large reductions in the number of receive cells that must be modeled for the range area, which reduces processing time by an order of magnitude.

6.3 MODELED SOURCE PATHS AND LOCATIONS

USWTR exercise participants are allowed to maneuver without restriction during a training exercise. To model the variable movement of exercise participants on each range, five representative moving source paths and three stationary source positions were chosen (see figure 6-5). The five paths correspond to one cross-slope track within each depth regime, combined with one upslope and one downslope track. No participant can move over the entire range area in a single exercise because of its limited duration (6 hours). These representative paths and positions are used to find the area for which the SEL and SPL are above the Level B harassment thresholds.

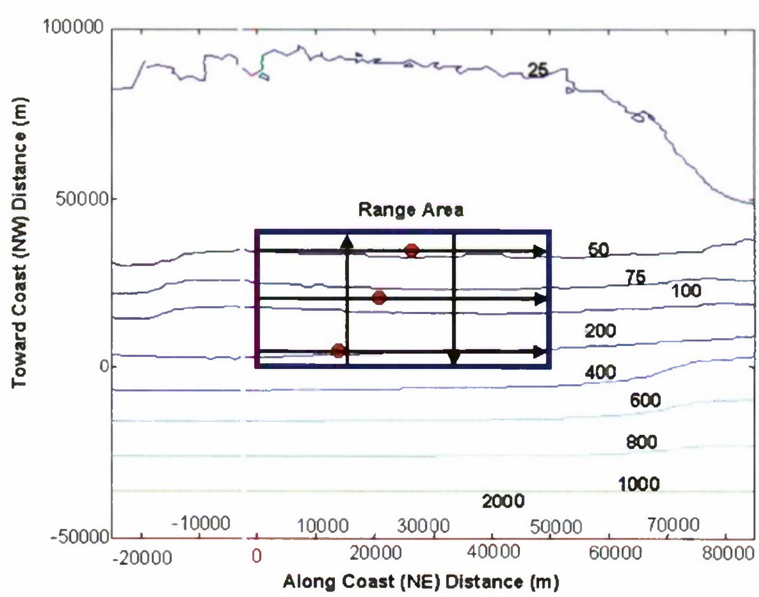

Figure 6-5. Ship Tracks and Stationary Points (Onslow Bay Analysis)

Omnidirectional, stationary sources are analyzed with a single acoustic footprint at the analysis point in each depth regime (that is, three footprints). For directional, stationary sources, three acoustic footprints are used for each depth regime: upslope, downslope, and cross-slope (that is, nine footprints). These footprints are averaged for calculating the harassment rates.

The acoustic output for moving sources was modeled along the five vessel tracks. These tracks include upslope, downslope, and cross-slope movement to capture beam pattern effects versus direction of travel. Ensuring that the mammal populations distributed within the analysis area intersect with one or more identified paths must be considered in selecting the paths.

The acoustic footprint for moving sources will change as a new depth regime is entered along the source path. Moving sources with directional footprints also use an acoustic footprint beam pattern orientation that reflects the direction of travel—upslope, downslope, or cross-slope.

6.4 RECEIVE CELL-LEVEL CALCULATIONS

RLs are calculated for each data cell within the entire analysis area. Because sound is not restricted from propagating outside the instrumented tracking area, receive cells extend 100 km beyond the range's boundary. The RL is recorded for each modeled ping in all cells overlapped by the acoustic footprint for each source. Any receive cell not overlapped by the acoustic footprint records no received ping.

To calculate receive cell-level for a moving source, the source is positioned at one end of the path being analyzed. The RLs are determined by overlaying the acoustic footprint on the source point and storing the footprint's values in all overlapped receive cells (conceptually shown in figure 6-6). The source is then moved along the source path to the next point, and the process is repeated. The distance between points is calculated from the vessel speed and the time interval between pings. For example, if a ship is moving at 18.5 km/hr (10 knots) and pinging at an interval of 30 seconds, the next analysis point would be 154.2 m farther along the path. Incrementing the source point location continues until the full path has been completed. Receive cell data are generated for every combination of source, season, and track.

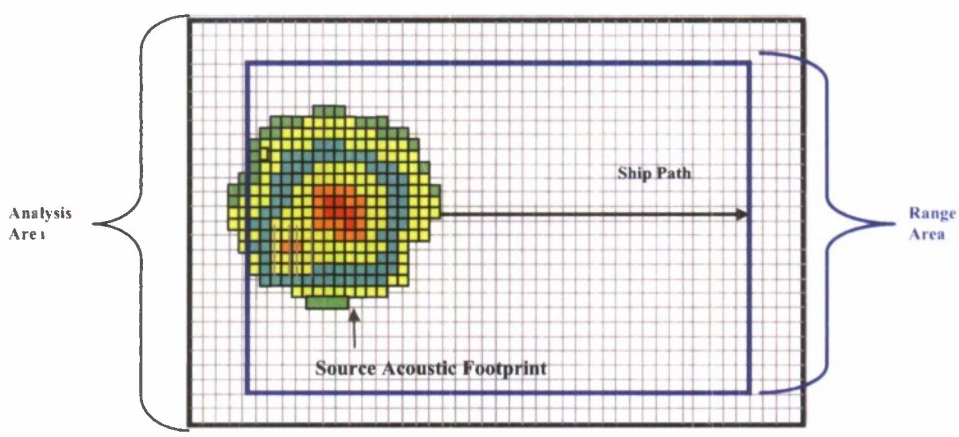

Figure 6-6. Modeling a Source's Movement Along a Track

Ping RL versus time for a single receive cell is plotted in figure 6-7. The graph represents a directional source's track passing directly over the cell, which produces an upslope in the RL as the source moves toward the cell. After the source passes the cell, the RL is zero because the cell is outside the source's horizontal beamwidth.

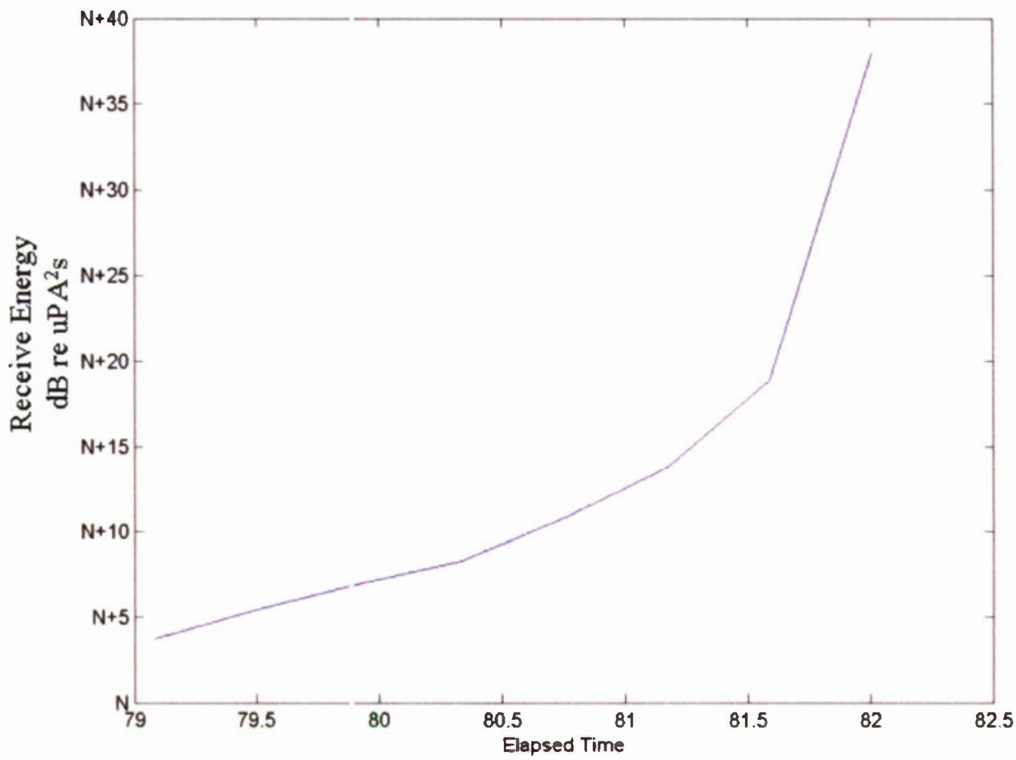

Figure 6-7. RL Versus Time for One Geographic Cell

The process for stationary sources is simpler. Their acoustic footprints are positioned at the fixed transmission points and the RLs are recorded in the cells. If multiple pings originate from a single point, such as with dipping sonar, the repetition rate and number of pings are modeled and the RLs are recorded in the same manner. Responses in three directions (upslope, downslope, and cross-slope) must be calculated and averaged as part of the analysis for directional stationary sources.

6.5 SEL CALCULATIONS

SEL calculations determine the accumulated level received at each geographic cell on the range from each ping signal; the results are stored in a three-dimensional matrix (x- and y-cell coordinates and accumulated RL). Calculating each cell's RL combines the acoustic footprint with source speed and other acoustic source characteristics, such as ping repetition rate. The matrix is uniquely calculated for each source's operational mode, depth, and season. Each of the two surface sonars have two modes, search and target, and the other sources have a single

operational mode. Sources with multiple operational depths are the ALFS, torpedo sonar, DICASS sonobuoy, and submarine sonar. The use of source paths allows the model to characterize variations in sound propagation over the range site (see section 6.3). Each cell corresponds to a specific region of the range area, for example, a 25- by 25-m square. The cell size was adjusted to be five times larger than the resolution used in the propagation analysis.

An acoustic energy (AE) map is a display of the SEL accumulated from a modeled source, taking into account the intensity, duration, and number of received pings. Total AE is calculated from the AE matrix data for each cell. The data for received pings within each cell are converted to a SEL value for that cell. A typical AE map is shown in figure 6-8. Areas along the source path are those having the highest total energy. Total energy decreases as distance from the vessel track increases. The acoustic footprint is adjusted as the source moves through depth regimes. In this example, the transmission point (red cell) for each individual ping can be observed. The track also shows the effect of the source's horizontal beamwidth.

A separate acoustic energy map is required to calculate exposures using risk function criteria (Level B behavioral). This second AE map records only the maximum SPL for each receive cell.

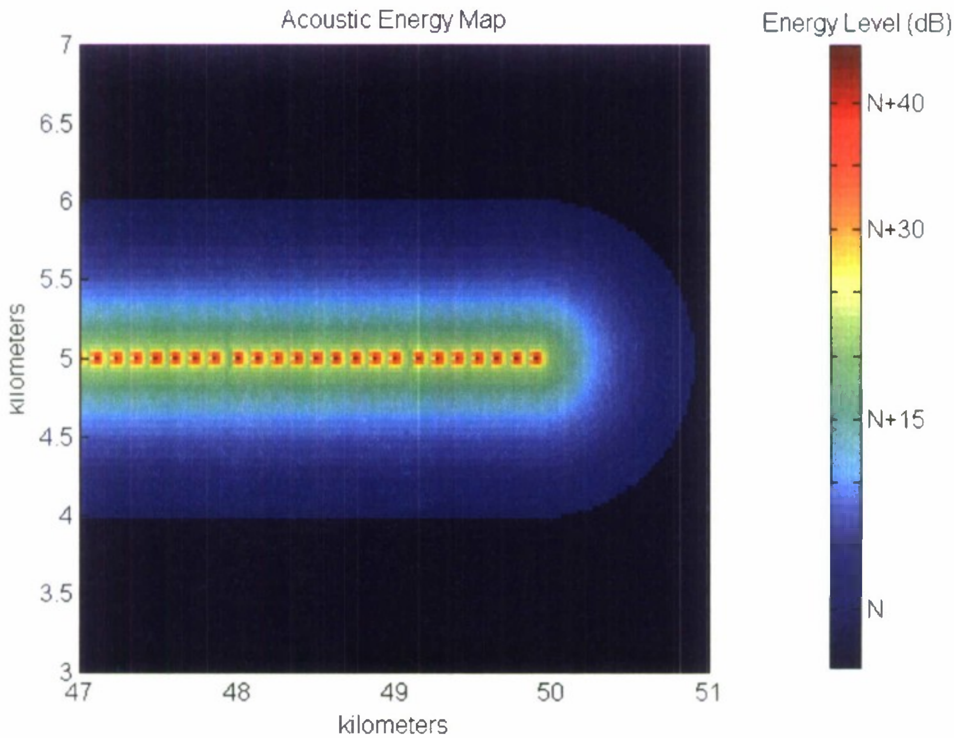

Figure 6-8. Portion of a Typical Acoustic Energy Map

6.6 MARINE MAMMAL THRESHOLD ANALYSIS AND EXPOSURE CALCULATION

Once the AE is calculated for a given source and source path, a determination can be made for each individual cell as to whether the Level B harassment thresholds have been exceeded. Level B TTS exposures are determined through a comparison of the total SEL with the Level B onset-TTS threshold. The comparison identifies cells above the threshold for the range area. Species exposures are then calculated by summing cells on the species density map that correspond to cells that exceeded Level B TTS on the AE map.

Level B behavioral exposures are determined by applying the risk function to cells containing SPLs between 120 and 195 dB re 1 μPa. Application of the risk curve consists of multiplying the risk (0.0 – 1.0) by the area of each cell. The next step is to multiply the resulting AE map by the species density map. The cells are then added to provide the species exposures.

The cell counts for both Level B TTS and behavioral exposures are converted to a total area for which the threshold has been exceeded, based on the modeled cell size. For example, if each cell is 25 m x 25 m and the number of cells above the threshold is 500, the total harassment area would be 0.3125 km^2. These harassment areas are exported to a spreadsheet that generates exposures estimates in a series of steps:

1. Harassment areas per acoustic source are converted into harassment rates.

2. Harassment rates are combined with mammal density maps to generate species harassment rates.

3. Operational scenario data for each acoustic source are applied to the species harassment rates to produce exposure estimates for each mammal.

4. Summary totals for Level A (PTS) and Level B (TTS and behavioral) exposure estimates are generated.

6.6.1 Acoustic Source Harassment Rate Calculation

Level A and Level B harassment rates are handled identically at this point, although harassment areas are derived from a separate analysis. The area for Level A is subtracted from that for Level B to prevent double-counting the area in exposure estimates. Additionally, harassment areas between 195 and 215 dB re 1 μPa SEL, representing Level B TTS exposures, are also subtracted from the remaining Level B harassment area prior to applying risk function curves to avoid double-counting. The total number of potential Level B harassment exposures is calculated by adding TTS exposures and risk function exposures; however, for the purposes of this report, the Level B exposures are stated separately.

The harassment rate for each acoustic source depends on its operation. Table 6-1 provides the harassment rate* definitions. Moving sources (surface sonars and dipping sonar) have harassment rates expressed in exposures/km. The total harassment area for each moving source is divided by the total track length (230 km) to produce a factor of harassment area per kilometer, which is also called exposures/km.

Stationary sources follow a process similar to that of moving sources, but the analysis calculates exposures/use rather than by distance. Average harassment area is determined on a per-use basis. If a source is horizontally directional, the exposure rate is an average based on the harassment area for the three directional orientations (upslope, downslope, and cross-slope) for each source position and depth modeled. The rate for AN/BQQ-5 submarine sonar is defined as exposures/ping. Torpedo sonars employ a definition of exposures/use, that is, exposures are estimated for each torpedo firing. Harassment rate calculations differ for each combination of source, season, and operational mode.

Table 6-1. Harassment Rate Definitions for Each Source

Source	Harassment Rate Definition
AN/SQS-53C Surface Sonar	Exposures/km of vessel movement
AN/SQS-56 Surface Sonar	Exposures/km of vessel movement
AN/BQQ-5 Submarine Sonar	Exposures/ping
Torpedo Sonar	Exposures/run
Helicopter Dipping Sonar	Exposures/km of helicopter movement
Fathometer, Surface Ship and Submarine	Exposures/km of vessel movement
DICASS	Exposures/use
CM	Exposures/use
NIXIE	Exposures/km of vessel movement

6.6.2 Species Harassment Rate Calculation

Species harassment rates are calculated by multiplying the harassment rate for each source use case (the combination of season, site, depth, mode, and effects threshold) by the appropriate species density estimates map. Recall that the harassment rate is an expression of harassment area in km^2. For each season, the product is calculated to produce a seasonal species harassment rate.

6.6.3 Exposure Estimate Calculations

Table 6-2 details the information used in exposure estimate calculations. This example is based on AN/SQS-53C surface sonar and saddleback (common) dolphins in autumn during scenario 2 for Wallops Island. The species harassment rate is multiplied by the total use of the

* These definitions actually pertain to the rate at which area above the harassment thresholds was generated by the source's operation.

source for the given scenario and season. For a moving source, the total distance spent pinging is required because the species harassment rate is expressed in harassment/km. Thus, the calculation incorporates source speed, exercise duration, operational duty cycle, and occurrences of each scenario by season as characterized in section 4.

Level B behavioral harassment occurs at received energy levels below what would elicit TTS. In this case, a risk function is applied. Specifically, the equation (7) was implemented in the analysis:

$$R(L) = \frac{1}{1+[K/(L-B)]^{A}}, \tag{7}$$

where,

R = risk (0.0 – 1.0);

L = receive level (RL in dB re 1 µPa);

B = basement RL in dB re 1 µPa (120 dB re 1 µPa);

K = RL increment above basement in dB re 1 µ Pa at the 50% risk level (45 dB re 1 µPa);

A = risk transition sharpness parameter (10 for odontocetes and pinnipeds; 8 for mysticetes).

This equation is mathematically equivalent to Feller's equation (6) (see section 3.3.2). This form, however, does not produce a discontinuity at L - B. The 99% RL was 195 dB re 1 µPa for mysticetes and odontocetes/pinnipeds.

Table 6-2. Example Saddleback (Common) Dolphin Level B TTS Exposures Estimate for AN/SQS-53C in Scenario 2 During Autumn at Wallops Island

Factor	Value
Yearly Scenario Occurrences	30
Scenario Duration	6 hours
Number of Surface Sonar Platforms in the Scenario	1
Number of Total Source AN/SQS-53C Platforms Used (70% of total surface sonars)	0.7
Number of AN/SQS-53C Sonar Platforms Used in Autumn	5.25
Operational Duty Cycle (split with Helicopters)	50%
Ship Speed (km/hr)	18.52
Search Mode Operational Percentage (split with track mode)	67%
Applicable Species Harassment Rate	0.0394744
AN/SQS-53C Search Mode Exercise Exposures	77.1457

7. RESULTS

7.1 JACKSONVILLE EXPOSURE ESTIMATE SUMMARIES

Tables 7-1 through 7-3 summarize the number of estimated exposures by sonar source, scenario, and mammal population for the Jacksonville site.

Table 7-1. Jacksonville Annual Exposure Estimate Summary by Source

Source	Level A PTS SEL ≥ 215	Level B TTS 215 > SEL ≥ 195	Level B Behavioral (Risk Function)
56X Search Mode	0.000	6.107	12032.813
56X Target Mode	0.000	2.003	5978.515
53C Search Mode	4.789	1471.824	58976.699
53C Target Mode	0.000	7.166	13004.079
Submarine Sonar	0.362	12.236	12168.391
Mk 48	0.000	4.216	391.682
ALFS	2.534	193.421	2490.031
DICASS	0.000	2.584	60.674
Fathometer, Surface Ship	0.000	0.000	0.008
Fathometer, Submarine	0.000	0.000	0.012
Mk 54	0.000	0.000	0.000
Mk 46	0.000	0.703	0.436
Mk 84 Pinger	0.000	0.000	1091.624
CM	0.137	1.231	142.293
NIXIE	0.000	0.000	69.315

Table 7-2. Jacksonville Annual Exposure Estimate Summary by Scenario

Scenario	Level A PTS SEL ≥ 215	Level B TTS 215 > SEL ≥ 195	Level B Behavioral (Risk Function)
1	2.091	158.921	2761.113
2	2.808	808.692	48217.060
3	0.394	14.826	12660.934
4	2.529	719.053	42767.466

Table 7-3. Jacksonville Annual Exposure Estimate Summary by Marine Mammal Population

Mammal	Level A PTS SEL ≥ 215	Level B TTS 215 > SEL ≥ 195	Level B Behavioral (Risk Function)
Bottlenose Dolphin	4.339	747.384	49756.949
Pilot Whales	0.062	23.611	1809.482
Saddleback Dolphin	0.000	0.000	0.000
Grampus	0.230	28.789	2554.386
All Beakcd Whales	0.000	0.037	28.246
Humpback Whales (E)	0.000	1.818	105.639
Sperm Whales (E)	0.000	0.000	0.000
Spotted Dolphins	2.806	808.232	46558.455
Clymene Dolphin	0.119	28.139	1713.101
North Atlantic Right Whale (E)	0.000	0.532	47.005
Pygmy Dwarf Sperm Whales	0.011	2.674	162.778
Rough Toothed Dolphin	0.005	1.270	77.356
Striped Dolphin	0.000	0.000	0.000
Minke Whale	0.000	0.106	7.407
Pantropical Dolphin	0.249	58.898	3585.769
Fin Whale (E)	0.000	0.000	0.000
Sei Whale (E)	0.000	0.000	0.000
Gray Seal	0.000	0.000	0.000
White-Sided Dolphin	0.000	0.000	0.000
(E) = Endangered Species			

7.2 CHARLESTON EXPOSURE ESTIMATE SUMMARIES

Tables 7-4 through 7-6 summarize the number of estimated exposures by sonar source, scenario, and mammal population for the Charleston site.

Table 7-4. Charleston Annual Exposure Estimate Summary by Source

Source	Level A PTS SEL ≥ 215	Level B TTS 215 > SEL ≥ 195	Level B Behavioral (Risk Function)
56X Search Mode	0.000	0.696	2116.222
56X Target Mode	0.000	0.000	0.000
53C Search Mode	0.000	170.914	3300.592
53C Target Mode	0.000	0.800	550.163
Submarine Sonar	0.000	13.707	856.101
Mk 48	0.000	0.685	240.072
ALFS	0.000	11.247	539.752
DICASS	0.000	0.296	56.327
Fathometer, Surface Ship	0.000	0.000	1.556
Fathometer, Submarine	0.000	0.000	2.334
Mk 54	0.000	0.000	0.000
Mk 46	0.000	0.000	0.132
Mk 84 Pinger	0.000	0.000	513.572
CM	0.053	0.445	0.236
NIXIE	0.000	0.000	18.650

Table 7-5. Charleston Annual Exposure Estimate Summary by Scenario

Scenario	Level A PTS SEL ≥ 215	Level B TTS 215 > SEL ≥ 195	Level B Behavioral (Risk Function)
1	0.016	9.455	790.720
2	0.006	92.691	3371.665
3	0.012	14.186	1097.773
4	0.019	82.459	2935.549

Table 7-6. Charleston Annual Exposure Estimate Summary by Marine Mammal Population

Mammal	Level A PTS SEL ≥ 215	Level B TTS 215 > SEL ≥ 195	Level B Behavioral (Risk Function)
Bottlenose Dolphin	0.021	75.822	3298.093
Pilot Whales	0.004	15.396	748.925
Saddleback Dolphin	0.000	0.000	0.000
Grampus	0.003	18.564	755.999
All Beaked Whales	0.000	0.000	0.003
Humpback Whales (E)	0.000	0.000	23.050
Sperm Whales (E)	0.000	0.000	0.003
Spotted Dolphins	0.000	0.000	2405.157
Clymene Dolphin	0.000	0.000	296.893
North Atlantic Right Whale (E)	0.000	0.000	4.282
Pgymy Dwarf Sperm Whales	0.000	0.675	28.473
Rough Toothed Dolphin	0.000	0.000	12.477
Striped Dolphin	0.000	0.000	0.000
Minke Whale	0.000	0.000	1.131
Pantropical Dolphin	0.000	0.000	621.222
Fin Whale (E)	0.000	0.000	0.000
Sei Whale (E)	0.000	0.000	0.000
Gray Seal	0.000	0.000	0.000
White-Sided Dolphin	0.000	0.000	0.000
(E) = Endangered Species			

7.3 ONSLOW BAY EXPOSURE ESTIMATE SUMMARIES

Tables 7-7 through 7-9 summarize the number of estimated exposures by sonar source, scenario, and mammal population for the Onslow Bay site.

Table 7-7. Onslow Bay Annual Exposure Estimate Summary by Source

Source	Level A PTS SEL ≥ 215	Level B TTS 215 > SEL ≥ 195	Level B Behavioral (Risk Function)
56X Search Mode	0.000	2.208	2273.641
56X Target Mode	0.000	0.741	1209.317
53C Search Mode	1.761	608.735	13600.091
53C Target Mode	0.000	2.621	2680.430
Submarine Sonar	0.187	10.488	18025.576
Mk 48	0.000	2.326	186.230
ALFS	0.000	17.264	3535.262
DICASS	0.000	0.925	105.569
Fathometer, Surface Ship	0.000	0.000	0.008
Fathometer, Submarine	0.000	0.000	0.012
Mk 54	0.000	0.000	0.000
Mk 46	0.000	0.254	0.172
Mk 84 Pinger	0.000	0.000	602.548
CM	0.048	0.596	80.811
NIXIE	0.000	0.000	24.629

Table 7-8. Onslow Bay Annual Exposure Estimate Summary by Scenario

Scenario	Level A PTS SEL ≥ 215	Level B TTS 215 > SEL ≥ 195	Level B Behavioral (Risk Function)
1	0.014	14.888	3327.572
2	0.938	327.868	10994.396
3	0.198	11.897	18276.524
4	0.846	291.504	9725.804

Table 7-9. Onslow Bay Annual Exposure Estimate by Marine Mammal Population

Mammal	Level A PTS SEL ≥ 215	Level B TTS 215 > SEL ≥ 195	Level B Behavioral (Risk Function)
Bottlenose Dolphin	0.906	239.840	21861.150
Pilot Whales	0.000	2.915	539.067
Saddleback Dolphin	0.000	0.000	1.165
Grampus	0.000	5.600	348.670
All Beaked Whales	0.000	0.000	3.114
Humpback Whales (E)	0.000	0.000	0.000
Sperm Whales (E)	0.000	0.000	0.041
Spotted Dolphins	0.813	304.308	14050.020
Clymene Dolphin	0.086	28.882	1704.117
North Atlantic Right Whale (E)	0.000	0.000	3.487
Pgymy Dwarf Sperm Whales	0.008	2.745	161.917
Rough Toothed Dolphin	0.003	1.305	76.949
Striped Dolphin	0.000	0.000	0.000
Minke Whale	0.000	0.109	7.636
Pantropical Dolphin	0.180	60.454	3566.964
Fin Whale (E)	0.000	0.000	0.000
Sei Whale (E)	0.000	0.000	0.000
Gray Seal	0.000	0.000	0.000
White-Sided Dolphin	0.000	0.000	0.000
(E) = Endangered Species			

7.4 WALLOPS ISLAND EXPOSURE ESTIMATE SUMMARIES

Tables 7-10 through 7-12 summarize the number of estimated exposures by sonar source, scenario, and mammal population for the Wallops Island site.

Table 7-10. Wallops Island Annual Exposure Estimate Summary by Source

Source	Level A PTS SEL ≥ 215	Level B TTS 215 > SEL ≥ 195	Level B Behavioral (Risk Function)
56X Search Mode	0.000	11.005	11430.218
56X Target Mode	0.000	0.000	5702.172
53C Search Mode	9.403	3570.075	64215.740
53C Target Mode	0.000	14.064	9113.088
Submarine Sonar	0.979	79.714	45124.306
Mk 48	0.000	15.285	1317.655
ALFS	0.000	62.709	10512.661
DICASS	0.000	4.880	363.437
Fathometer, Surface Ship	0.000	0.000	0.008
Fathometer, Submarine	0.000	0.000	0.012
Mk 54	0.000	0.000	0.000
Mk 46	0.000	1.206	1.003
Mk 84 Pinger	0.000	0.000	2933.533
CM	0.247	2.014	230.909
NIXIE	0.000	0.000	108.305

Table 7-11. Wallops Island Annual Exposure Estimate by Scenario

Scenario	Level A PTS SEL ≥ 215	Level B TTS 215 > SEL ≥ 195	Level B Behavioral (Risk Function)
1	0.073	55.237	10618.930
2	5.007	1915.064	49870.331
3	1.037	88.525	46527.630
4	4.512	1702.125	44036.156

Table 7-12. Wallops Island Annual Exposure Estimate Summary by Marine Mammal Population

Mammal	Level A PTS SEL ≥ 215	Level B TTS 215 > SEL ≥ 195	Level B Behavioral (Risk Function)
Bottlenose Dolphin	0.212	80.087	6640.133
Pilot Whales	0.133	31.267	3632.056
Saddleback Dolphin	9.240	3329.034	119211.559
Grampus	0.169	46.137	2243.339
All Beaked Whales	0.000	0.496	127.614
Humpback Whales (E)	0.000	0.000	0.000
Sperm Whales (E)	0.000	1.108	268.196
Spotted Dolphins	0.000	0.724	80.299
Clymene Dolphin	0.086	31.646	1421.163
North Atlantic Right Whale (E)	0.000	0.359	15.533
Pgymy Dwarf Sperm Whales	0.008	3.007	135.029
Rough Toothed Dolphin	0.003	1.430	64.171
Striped Dolphin	0.597	167.531	14148.420
Minke Whale	0.000	0.120	6.185
Pantropical Dolphin	0.180	66.238	2974.706
Fin Whale (E)	0.000	1.766	84.644
Sei Whale (E)	0.000	0.000	0.000
Gray Seal	0.000	0.000	0.000
White-Sided Dolphin	0.000	0.000	0.000
(E) = Endangered Species			

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